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Status of Oxygen-Activated Sludge Wastewater Treatment

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This publication provides an updated status report on the number and type of oxygen-activated sludge facilities in operation, under construction, and being designed. It describes in detail the latest EPA supported oxygenation research and demonstration project, an evaluation of the RAD version of the open realtor system being carried out at the Metropolitan Denver, Colorado Sewage Treatment Plant. Several on-line oxygen wastewater treatment systems are summarized as to their design, operating, and performance.

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STATUS OF OXYGEN-ACTIVATED SLUDGE WASTEWATER TREATMENT

U.S. ENVIRONMENTAL PROTECTION AGENCY
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October 1977

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NOTICE

The mention of trade names or commercial products in this publication is for illustration purposes, and does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

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INTRODUCTION

In the past eight years, the use of oxygen gas in the activated sludge process has evolved from a level of primarily academic interest to a point of broad application and implementation. A large and rapidly growing number of oxygen-activated sludge plants are in operation in North America and Japan. Several plants will soon be operational in Europe. Included among the operating facilities are installations treating process wastewaters from six major industrial categories. By 1980, it is projected that construction will be completed on approximately 150 oxygen systems with a combined hydraulic capacity between 5 and 6 bgd (219 to 263 cu m/sec).

Beginning with the initial research project conducted at Batavia, New York, in 1968 and 1969 (1), the development and refinement of oxygenation technology has been more rapid than normally associated with wastewater treatment processes. Design engineers today can select from several oxygen dissolution concepts including both covered and open reactor alternatives. The covered reactor UNOX and OASES systems (marketed by the Union Carbide Corporation and Air Products and Chemical) are available with either surface aerators or submerged turbines. The surface aerator option has become the standard covered reactor design except in cases where unusually deep tanks are specified. Two versions of open reactor MAROX system (marketed by the FMC Corporation), one utilizing rotating active diffusers (RAD's), the other fixed active diffusers (FAD's), are also marketed. At this time, the second generation RAD design appears to be a significant cost-effective improvement compared to the original FAD design.

The purposes of this publication are:

1. To provide an updated status report on the number and type of oxygen-activated sludge facilities in operation, under construction, and being designed.

2. To describe in detail the latest EPA supported oxygenation research and demonstration project, an evaluation of the RAD version of the open reactor system being carried out at the Metropolitan Denver, Colorado Sewage Treatment Plant.

3. To summarize design, operating, and performance information for several on-line oxygen wastewater treatment systems.

Chapter 1

STATUS REPORT

A complete listing of the 50 oxygen-activated plants that were in operation as of June 1976 is presented in Table 1-1. The 66 oxygenated plants under construction on the same date are listed in Table 1-2. An additional 41 oxygenation plants were in various stages of design during June 1976; these plants are listed in Table 1-3.

All three tables provide design flow and oxygen supply data (where known) for each plant location listed, as well as identifying the wastewater application. Multiple oxygen process applications, such as carbonaceous organics removal plus nitrification, aerobic digestion, ozonation, etc., are also noted where applicable. In addition, Tables 1-1 and 1-2 include information on the oxygen supply systems selected. This latter information is not given in Table 1-3 because these plants have either not yet been bid or litigation has delayed awarding of contracts to specific oxygen system suppliers.

Perusal of Table 1-3 reveals that no industrial wastewater applications are shown in the "plants being designed" list. This omission is not intended to indicate that there were no industrial plants in the design phase as of June 1976, but rather that the identity of such plants is confidential proprietary information until after equipment purchase contracts are awarded.

Data on the number of plants, design flows and oxygen supply capacities have been extracted from Tables 1-1, 1-2 and 1-3 and condensed in Table 1-4. The same information is presented in Table 1-5 for United States oxygen plants. These two tables indicate that as of June 1976 only about 12 percent of the firm planned oxygen design flow capacity was actually completed and in operation. On-line capacity is expected to increase 7-8 times, however, in the next 4-5 years. Approximately 25 percent of the oxygen installations included in the Table 1-4 totals were treating or will treat industrial process wastewaters. Excluding the Japanese plants for which oxygen supply data were unavailable to the writer, the design oxygen supply capacity averages 3.07 tons/mil gal of design flow (7.4×10^{-4} metric ton/cu m) for the industrial applications compared to 1.34 tons/mil gal of design flow (3.2×10^{-4} metric ton/cu m) for the municipal applications.

A breakdown, by country, of the 157 known operating and planned oxygen installations is given in Table 1-6. Eighty-five percent of these installations are or will be located in the United States and 11 percent in Japan. The remaining 4 percent are divided among seven other countries each with one plant.

The detailed information provided in Tables 1-1 and 1-2 on oxygen dissolution and oxygen generation systems is summarized in Table 1-7. In most cases, the vendor supplying the oxygen dissolution equipment was also awarded the oxygen supply system contract. The preponderance of surface aerators over submerged turbines in covered reactor systems is illustrated in Table 1-7 and is attributed to the lower overall costs and maintenance requirements of the aerator option. Surface aerators are being or will be used in 93 percent of the covered reactor systems with specified dissolution equipment, submerged turbines in 6 percent, and a combination of both in one system. Plants employing submerged turbines have deep aeration tanks, typically greater than 20 ft (6.1 m), and tend to be larger than 100 mgd (4.4 cu m/sec) in size. Conversely, the average design flow of the 103 surface aerator systems is only about 18 mgd (0.8 cu m/sec).

Table 1-1. ***Oxygen-Activated Sludge Plants in Operation as of June 1976***

Location	Design Flow (mgd)	Installed O_2 Supply Capacity (tons/day)	Application‡	O_2 Dissolution Systems§	O_2 Supply Systems∝
USA					
1. Alton Box Board - Jacksonville, Fla.	6	25	I-PP	UNOX (A)	CRYO
2. Baychem Corp., Chemagro Div. - Kansas City, Kan.	4.32	50	I-C	UNOX (A)	CRYO
3. Brunswick, Ga.	10	16	M	UNOX (A)	PSA
4. Chaska, Minn.	1.25	1.25	M	OASES (A)	LIQ
5. Chesapeake Corp. - West Point, Va.	16.25	34	I-PP	UNOX (A)	CRYO
6. Container Corp. - Fernandino Beach, Fla.	25	50	I-PP (b)	UNOX (A)	CRYO
7. Decatur, Ill.	17	17	M	UNOX (A)	PSA
8. Deer Park, Tex.	5	6	M	UNOX (A)	PSA
9. Denver (#2), Colo.	10	7.5	M	MAROX (R)	LIQ
10. Detroit (#1), Mich.	300	180	M	UNOX (T)	CRYO
11. Fairfax County, Va.	14	10	M	OASES (A)	LIQ
12. Fayetteville, N.C.	14	18	M	OASES (A)	CRYO
13. Fibreboard Corp. - Antioch, Calif.	16	35	I-PP(b)	UNOX (A)	PIPE
14. Ft. Myers, Fla.	5	9	M	UNOX (A)	PSA
15. French Paper Co. - Niles, Mich.	0.8	1	I-PP	UNOX (A)	LIQ
16. Gulf States Paper Corp. - Tusaloosa, Ala.	10	30	I-PP	UNOX (A)	PSA
17. Hamburg (#1), N.Y.	1	0.5	M	UNOX (A)	LIQ
18. Hercules, Inc. - Wilmington, N.C.	1	15	I-C	UNOX (A)	PIPE
19. Hollywood, Fla.	36	50	M	OASES (A)	CRYO
20. Jacksonville (#1), Fla.	5	20	M	UNOX (A)	PSA
21. Lederle Laboratories Div. of American Cyanamid-Pearl River, N.Y.	1.5	15	I-PH	UNOX (A)	PSA
22. Littleton, Colo.	1.5	0.5	M(d)	UNOX (A)	LIQ
23. Morganton, N.C.	8	26	M	UNOX (A)	PSA
24. Morrisville, Pa.	4.6	4	M	UNOX (A)	PSA
25. Newtown Creek - New York City, N.Y.	20	14	M	UNOX (T)	PSA
26. North Lauderdale, Fla.	2	1	M(d)	UNOX (A)	LIQ
27. Quail Valley, Tex.	1.5	2	M	UNOX (A)	PSA
28. Speedway, Ind.	7.5	4	M	UNOX (A)	PSA
29. Standard Brands - Peeksville, N.Y.	1	5	I-FP	UNOX (A)	LIQ
30. Union Carbide Corp. - Marietta, Ga.	1.26	1	I-C	UNOX (A)	LIQ
31. Union Carbide Corp.- Sistersville, W. Va.	4.33	15	I-C	UNOX (A)	PIPE
32. Union Carbide Corp. - Taft, La.	3.8	88	I-PC	UNOX (T)	PIPE
33. Weyerhauser Corp. - Everett, Wash.	3	25	I-PP	UNOX (A)	PIPE
34. Wyandotte, Mich.	100	60	M	UNOX (T)	PSA
35. Yuba City, Calif.	7	21	M	UNOX (A)	PSA
TOTAL	664.61	856.75			

Table 1-1. ***(Continued)***

Location	Design Flow (mgd)	Installed O2 Supply Capacity (tons/day)	Application‡	O2 Dissolution Systems§	O2 Supply Systems∝
Canada					
1. Winnipeg, Manitoba	12	10	M	UNOX (A)	PSA
Japan					
1. Electro Chemical Industrial Co. - Ichihara City	2.64	n.d.**	I-PC	UNOX (A)	n.d.**
2. Gotsu Plant - Katano City	0.73	n.d.	M	UNOX (A)	n.d.
3. Ikuta Plant - Kawasaki City	0.61	n.d.	M	UNOX (A)	n.d.
4. Jujo Paper - Kushiro City	1.59	n.d.	I-PP	UNOX (A)	n.d.
5. Kasuga Plant - Oita City	0.26	n.d.	M	UNOX (A)	n.d.
6. Mitsubishi Chemical Industries -	1.9	n.d.	I-PC	UNOX (A)	n.d.
7. Nissho Kayaku Petrochemical Complex - Oita City	0.74	n.d.	I-PC	UNOX (A)	n.d.
8. Oji Paper - Kasugai City	18.5	n.d.	I-PP	UNOX (A)	n.d.
9. Oji Paper - Tomakomai City	13.2	n.d.	I-PP	UNOX (A)	n.d.
10. Sanyo Kakusaku Pulp - Iwakuni City	0.89	n.d.	I-PP	UNOX (A)	n.d.
11. Showa Neoprene - Kawasaki City	0.79	n.d.	I-SR	UNOX (A)	n.d.
12. Sumitomo Chemical - Ichihara City	0.79	n.d.	I-PC	UNOX (A)	n.d.
13. Uenodai Plant, Japan Housing Corp. - Kamifukuoka City	0.52	n.d.	M	UNOX (A)	n.d.
14. Yakult Pharmaceutical Industries - Osaka City	0.19	n.d.	I-PH	MAROX (R)	n.d.
TOTAL	43.35				

‡I-C = Industrial-Chemicals
I-FP = Industrial-Food Processing
I-PC = Industrial-Petrochemical
I-PH = Industrial-Pharmaceutical
I-PP = Industrial-Pulp & Paper
I-SR = Industrial- Synthetic Rubber
M = Municipal
(b) = Conventional 0_2 treatment plus black liquor oxidation
(d) = Conventional O_2 treatment plus aerobic sludge digestion

§MAROX = FMC Corp.
OASES = Air Products & Chemicals, Inc.
UNOX = Union Carbide Corp.
(A) = Surface aerators (with or without bottom mixers)
(F) = Fixed active diffusers
(R) = Rotating active diffusers
(T) = Submerged turbines

∝CRYO = On-site liquid oxygen gas generation
LIQ = On-site liquid oxygen storage and vaporization
PIPE = Pipeline transport of oxygen gas from a nearby off-site oxygen generating facility
PSA = On-site pressure swing adsorption oxygen gas generation

**n.d. = no data.

Table 1-2. ***Oxygen-Activated Sludge Plants Under Construction as of June 1976***

Location	Design Flow (mgd)	Installed O_2 Supply Capacity (tons/day)	Application‡	O_2 Dissolution Systems§	O_2 Supply Systems∝
USA					
1. Appleton Papers Div. of N.C.F. - Appleton, Wisc.	6.5	14	I-PP	UNOX (A)	PSA
2. Baltimore, Md.	70	75	M	UNOX (A)	CRYO
3. Baton Rouge, La.	16	12	M	UNOX (A)	PSA
4. Broken Arrow, Okla.	4	3.5	M(d)	UNOX (A)	LIQ
5. Cedar Rapids, Iowa	33	120	M	UNOX (A)	CRYO
6. Chicopee, Mass.	15.5	17	M	UNOX (A)	PSA
7. Cincinnati, Ohio	1.2	50	M(Z)	UNOX (A)	CRYO
8. Crown Zellerbach Corp. - Antioch, Calif.	5.5	10	I-PP	UNOX (A)	PSA
9. Dade County (North), Fla.	60	100	M	OASES (A)	CRYO
10. Danville, Va.	24	33	M	UNOX (A)	PSA
11. Denver (#1), Colo.	72	80	M	UNOX (A)	CRYO
12. Detroit (#2), Mich.	600	450	M	OASES(T&A)	CRYO
13. Dow Chemical Co. - Plaquemine, La.	12.7	69	I-C	UNOX (A)	PIPE
14. Dubuque, Iowa	16	26	M	OASES (A)	CRYO
15. Duluth, Minn.	43.6	80	M	UNOX (A)	CRYO
16. East Bay Municipal Utility District (#1) - Oakland, Calif.	120	250	M	UNOX (T)	CRYO
17. East Bay Municipal Utility District (#2) - Oakland, Calif.	1.5	1.5	M	MAROX (R)	PIPE
18. Euclid, Ohio	22	28	M	UNOX (A)	PSA
19. Exon Chemical Co.-Baton Rouge, La.	9	35	I-PC	UNOX (A)	CRYO
20. Fairbanks, Alaska	8	13	M(d)	UNOX (A)	PSA
21. Fond du Lac, Wisc.	11	26	M	UNOX (A)	PSA
22. Ft. Lauderdale, Fla.	22	55	M(n)	OASES (A)	CRYO
23. Harrisburg, Pa.	35.4	50	M	UNOX (A)	CRYO
24. Hillsboro, Ore.	15	9	M	UNOX (A)	PSA
25. Hopewell, Va.	57.63	100	M	UNOX (A)	CRYO
26. Hot Springs, Ark.	12.1	11.5	M	UNOX (A)	PSA
27. Jacksonville (#2), Fla.	5	16	M	UNOX (A)	PSA
28. Kittanning, Pa.	1.5	1	M	UNOX (A)	PIPE
29. Lewisville, Tex.	6	7	M	UNOX (A)	PSA
30. Littleton/Englewood, Colo.	20	21	M	MAROX (R)	CRYO
31. Longview Fiber - Longview, Wash.	30	40	I-PP	UNOX (A)	CRYO
32. Louisville, Ky.	105	100	M	UNOX (T)	CRYO
33. Loxahatchee, Fla.	4	9	M(n)	UNOX (A)	PSA
34. Mahoning County, Ohio	4	7	M(n)	UNOX (A)	PSA
35. Miami, Fla.	55	80	M	UNOX (A)	CRYO
36. Middlesex, N.J.	120	450	M(d)	UNOX (T)	CRYO
37. Minneapolis, Minn.	1	1	M	MAROX (F)	LIQ
38. Mobile, Ala.	28	26	M	UNOX (A)	PSA
39. Mosinee Paper Corp.-Mosinee, Wisc.	6	13	I-PP	UNOX (A)	PSA
40. Muscatine, Iowa	13	80	M	UNOX (A)	CRYO
41. Nekoosa Papers, Inc. Port Edwards, Wisc.	35	52.8	I-PP(b)	UNOX (A)	CRYO
42. New Orleans, La.	122	140	M	OASES (A)	CRYO
43. North San Mateo, Calif.	8	10	M	UNOX (A)	PSA
44. Pensacola, Fla.	24	40	M(n&o)	OASES (A)	CRYO
45. Philadelphia (Southwest), Pa.	210	90	M	UNOX (A)	CRYO
46. Pima County, Ariz.	25	22	M	UNOX (A)	PSA

Table 1-2. ***(Continued)***

Location	Design Flow (mgd)	Installed O2 Supply Capacity (tons/day)	Application‡	O2 Dissolution Systems§	O2 Supply Systems*
47. St. Regis Paper Co. - Tacoma, Wash.	34	40	I-PP	UNOX (A)	CRYO
48. Salem, Ore.	26.5	36	M	UNOX (A)	PSA
49. Shell Oil Co. - Norco, La.	4.3	50	I-PC	UNOX (A)	CRYO
50. Springfield, Mo.	30	36	M(O_3)	UNOX (A)	PSA
51. Sunkist Growers, Lemon Products Div. - Corona, Calif.	1.75	50	I-FP	UNOX (A)	CRYO
52. Tahoe/Truckee, Calif.	8	4	M	UNOX (A)	PSA
53. Tampa, Fla.	51	120	M(n)	UNOX (A)	CRYO
54. Tauton, Mass.	8.4	20	M(n)	UNOX (A)	CRYO
55. Thilmany Pulp & Paper Co. - Kaukauna, Wisc.	22	10	I-PP	UNOX (A)	PSA
56. Tonawanda, N.Y.	30	32	M	UNOX (A)	CRYO
57. Two Bridges, N.J.	7.5	6	M	UNOX (A)	PSA
TOTAL	2339.58	3328.3			
Mexico					
1. Fundidora Steel Co. - Monterrey	13.7	12.7	I-S	UNOX (A)	PIPE
Europe					
1. ARA BIRS II, Switzerland	18	20	M	UNOX (A)	PSA
2. Bayer-Elberfeld - Dusseldorf, Germany	1.8	50	I-C	UNOX (A)	CRYO
3. Copenhagen, Denmark	110	160	M	UNOX (A)	CRYO
4. Palmersford, England	1.2	2	M(n)	UNOX (A)	PSA
5. Union Carbide Belgium - Antwerp, Belgium	0.71	16	I-C	UNOX (A)	PSA
TOTAL	131.71	248			
Japan					
1. Mitsubishi Chemical Industries - Kitakyushu City	3.09	n.d.**	I-DS	UNOX (A)	n.d.**
2. Mitsui Toatsu Chemicals - Takaishi City	1.71	n.d.	I-PC	UNOX (A)	n.d.
3. Tokiwa Sangyo - Owari Asahi City	3.7	n.d.	I-PP	UNOX (A)	n.d.
TOTAL	8.50				

‡I-C = Industrial-Chemicals
I-DS = Industrial-Dyestuffs
I-FP = Industrial-Food Processing
I-PC = Industrial-Petrochemical
I-PP = Industrial-Pulp & Paper
I-S = Industrial-Steel
M = Municipal
(b) = Conventional O2 treatment plus black liquor oxidation
(d) = Conventional O2 treatment plus aerobic sludge digestion
(n) = Conventional O2 treatment plus nitrification
(o) = Conventional O2 treatment plus effluent ozonation
(Z) = Treatment of Zimpro supernatant only

§MAROX = FMC Corp.
OASES = Air Products & Chemicals, Inc.
UNOX = Union Carbide Corp.
(A) = Surface aerators (with or without bottom mixers)
(F) = Fixed active diffusers
(R) = Rotating active diffusers
(T) = Submerged turbines

*CRYO = On-site cryogenic oxygen gas generation
LIQ = On-site liquid oxygen storage and vaporization
PIPE = Pipeline transport of oxygen gas from a nearyby off-site oxygen generating facility
PSA = On-site pressure swing adsorption oxygen gas generation

**n.d. = no data

Table 1-3. ***Oxygen-Activated Sludge Plants Being Designed as of June 1976***

Location	Design Flow (mgd)	Design O_2 Supply Capacity (tons/day)	Application‡
USA			
1. Amherst, N.Y.	24	40	M
2. Augusta, Me.	8	9	M
3. Baldwinsville, N.Y.	9	19	M
4. Clay, N.Y.	10	10	M
5. Clinton, N.C.	3	9	M
6. Concord, N.C.	25	80	M
7. Dade County (South), Fla.	40	130	M
8. Easton, Pa.	10	14	M
9. Greenville, S. C.	5	8	M
10. Hamburg (South Towns), N.Y.	12	14	M
11. Hampton Roads Sanitary District, Va.			
(a) Army Base	19	21	M
(b) Atlantic	36	40	M
(c) Boat Harbor	26	30	M
(d) Lamberts Point	37	42	M
12. Hannibal, Mo.	4.25	9	M
13. Holyoke, Mass.	22	22	M
14. Houston, Tex.	200	305	M
15. Indianapolis (Belmont), Ind.	125	180	M
16. Indianapolis (Southport), Ind.	125	180	M
17. Kansas City, Kan.	54	80	M
18. Kaukauna, Wisc.	6.1	13	M
19. Lebanon, Pa.	8	24	M
20. Los Angeles (Hyperion), Calif.	330	340	M
21. Los Angeles County (JWPCP), Calif.	500	500	M
22. Maryland City, Md.	4	7	M
23. Montgomery County, Pa.	10	14	M
24. Monticello, N.Y.	6	6	M
25. Murfreesboro, Tenn.	8	13	M
26. New Rochelle, N.Y.	14	16	M
27. Orlando, Fla.	24	50	M
28. Passaic Valley, N.J.	300	1000	M
29. Philadelphia (Northeast), Pa.	150	100	M
30. Philadelphia (Southeast), Pa.	100	80	M
31. Red Springs, N.C.	1.5	5	M
32. Sacramento, Calif.	150	200	M
33. San Francisco, Calif.	180	100	M
34. South Cobb County, Ga.	24	40	M
35. Sussex County, Del.	8	11	M
36. Tri-Municipal Sanitary District Poughkeepsie, N.Y.	14	9	M
37. York, Pa.	8	13	M
38. Texas City, Tex.	7.5	11	M
TOTAL	2647.35	3794	

‡M = Municipal

Table 1-4. *Worldwide Oxygen Plant Status — June 1976*

Parameter	Operating Plants	Plants Under Construction	Plants Being Designed	Total
No. of Plants				
Municipal	26	49	41	116
Industrial	24	17	--	41
Total	50	66	41	157
Design Flow (mgd)				
Municipal	584.5	2302	2647.3	5533.8
Industrial	135.5	191.5	--	327.0
Total	720.0	2493.5	2647.3	5860.8
O_2 Supply Capacity† (tons/day)				
Municipal	477.7	3126.5	3794	7398.2
Industrial	389	426.5	--	851.5
Total	866.7	3553.0	3794	8249.7

†Oxygen supply figures shown do not include data for Japanese plants.

Table 1-5. *USA Oxygen Plant Status — June 1976*

Parameter	Operating Plants	Plants Under Construction	Plants Being Designed	Total
No. of Plants				
Municipal	21	46	41	108
Industrial	14	11	--	25
Total	35	57	41	133
Design Flow (mgd)				
Municipal	570.3	2172.8	2647.3	5390.4
Industrial	94.3	166.8	--	261.1
Total	664.6	2339.6	2647.3	5651.5
O_2 Supply Capacity (tons/day)				
Municipal	467.7	2944.5	3794	7206.2
Industrial	389	383.8	--	772.8
Total	856.7	3328.3	3794	7979.0

Table 1-6. *Breakdown of Oxygen Plants by Country — June 1976*

Country	No. of Plants			
	Operating	Under Construction	Being Designed	Total
1. USA	35	57	41	133
2. Japan	14	3	-	17
3. Canada	1	-	-	1
4. Mexico	-	1	-	1
5. England	-	1	-	1
6. Germany	-	1	-	1
7. Denmark	-	1	-	1
8. Switzerland	-	1	-	1
9. Belgium	-	1	-	1
Total	50	66	41	157

Cryogenic oxygen gas generators are sold by several firms in the United States, whereas Union Carbide is the only known U.S. manufacturer of pressure swing adsorption (PSA) oxygen gas generators. The break-even range determined by Union Carbide for these two oxygen supply systems is approximately 20-25 tons/day (18-23 metric tons/day). Below this range, it is more cost effective to use PSA generators; above this range, cryogenic generators are more cost effective. Other manufacturers have developed mini-cryogenic oxygen generators to compete for the lower tonnage plants. On-site cryogenic or PSA gas generation was selected for 80 percent of the 99 oxygen-activated sludge plants with defined methods of oxygen supply, as of June 1976. The average capacities for these 79 supply systems are 92 tons/day (83 metric tons/day) for the cryogenic units and 16.2 tons/day (14.8 metric tons/day) for the PSA units.

Table 1-7. ***Summary of Oxygen Systems — June 1976***

Parameter	Operating Plants	Plants Under Construction	Total
Reactor Type (No.)			
Covered Reactor	48	63	111
Open Reactor	2	3	5
Total	50	66	116
O_2 Dissolution System Type (No.)			
Covered -Surface Aerators	44	59	103
Covered - Submerged Turbines	4	3	7
Covered - Combination of Aerators and Turbines	0	1†	1
Open - Rotating Active Diffusers	2	2	4
Open - Fixed Active Diffusers	0	1	1
Total	50	66	116
O_2 Supply System Type (No.)			
On-Site Cryogenic Generation	7	31	38
On-Site PSA Generation	15	26	41
On-Site Liquid Storage and Vaporization	9	2	11
Off-Site Pipeline Transport	5	4	9
Unknown*	14	3	17
Total	50	66	116
O_2 Supply System Capacity (ton/day)			
On-Site Cryogenic Generation	407	3086.8	3493.8
On-Site PSA Generation	254	413.5	667.5
On-Site Liquid Storage and Vaporization	27.8	4.5	32.3
Off-Site Pipeline Transport	178	84.2	262.2
Total	866.8	3589.0	4455.8
O_2 Dissolution System Design Flow (mgd)			
Covered - Surface Aerators	286	1526	1812
Covered - Submerged Turbines	423.8	345	768.8
Covered - Combination of Aerators and Turbines	0	600†	600
Open - Rotating Active Diffusers	10.2	21.5	31.7
Open - Fixed Active Diffusers	0	1	1
Total	720.0	2493.5	3213.5

†The oxygen dissolution system for Detroit's second-phase construction consists of submerged turbines in the lead stages and surface aerators in the rear stages.

*Data unavailable for Japanese oxygen supply systems.

Pipeline transport of off-site generated oxygen gas to an oxygenation wastewater treatment plant can be an economical choice of oxygen supply if the logistics are reasonable and if the off-site facility (e.g., a steel production plant) has extra generation capacity. This method of oxygen supply accounts for 9 percent of the defined supply systems and 6 percent of the June 1976 "operating" and "under construction" capacity. On-site storage and vaporization of trucked-in liquid oxygen, because of its high unit cost, is generally confined to requirements of 5 tons/day (4.5 metric tons/day), or less. The oxygen consumption of the 11 such systems documented in Table 1-7 is expected to average 2.9 tons/day (2.6 metric tons/day). This amounts to only 0.7 percent of the defined oxygen supply capacity.

Oxygen plants treating or scheduled to treat industrial wastewaters are broken down by industrial application in Table 1-8. Eight major categories are represented in the "operating" and "under construction" classifications. The pulp and paper industry leads the list with nearly one-half of the total plants and over three-fourths of the total design flow. The next most frequent users to date have been the petrochemical and chemical industries. Inasmuch as oxygenation technology is well suited to satisfying the high oxygen demand associated with many industrial wastewaters, continuing rapid growth in the oxygen industrial market is anticipated for years to come.

Table 1-8. ***Breakdown of Oxygen Plants by Industrial Application — June 1976***

Industrial Application	Operating Plants		Plants Under Construction		Total	
	No. of Plants	Design Flow (mgd)	No. of Plants	Design Flow (mgd)	No. of Plants	Design Flow (mgd)
1. Chemicals	4	10.9	3	15.2	7	26.1
2. Dyestuffs	0	0	1	3.1	1	3.1
3. Food Processing	1	1	1	1.8	2	2.8
4. Petrochemical	5	9.9	3	15.0	8	24.9
5. Pharmaceutical	2	1.7	0	0	2	1.7
6. Pulp & Paper	11	111.2	8	142.7	19	253.9
7. Steel	0	0	1	13.7	1	13.7
8. Synthetic Rubber	1	0.8	0	0	1	0.8
Total	24	135.5	17	191.5	41	327.0

Chapter 2

DESCRIPTION OF SECOND GENERATION OPEN REACTOR OXYGEN SYSTEM (MAROX)

The covered reactor oxygen system, including both the surface aerator and submerged turbine alternatives, has been described previously in the Proceedings of the Second U.S.–Japan Conference on Sewage Treatment Technology (2) and elsewhere (3). A description of the first generation fixed active diffuser (FAD) version of the open reactor oxygenation system was also provided in these documents. It is not deemed necessary to reiterate those descriptions here; however, certain characteristics of the covered reactor systems and the FAD open reactor system are compared with the second generation open reactor option, described below.

A section view of the key element (the rotating active diffuser (RAD)) is shown in Figure 2-1. As indicated, the basic RAD consists of a 7-ft (2.1-m) diameter submerged rotating plate mounted to the bottom of a 6-5/8-inch (16.8-cm) diameter hollow shaft approximately 3 ft (0.9 m) above the aeration tank floor. A 7-1/2-inch (19.1-cm) wide ceramic diffusion medium is inserted into preformed openings top and bottom around the periphery of the plate, forming two circular diffusion bands parallel to the outer tapered edge. Approximate 28-inch (71-cm) diameter radial impellers mounted to the top and bottom of the plate provide essential mixing of oxygen, substrate, and biomass. An optional surface impeller can be installed to aid in foam breakup, if desired. The relatively low design rotational velocity of 75-85 rpm is achieved with a constant speed motor and an appropriate gear reduction unit. The composite submerged assembly is illustrated in a cutaway perspective view in Figure 2-2.

A functional flow diagram for a typical MAROX system employing RAD's for oxygen transfer is presented in Figure 2-3. The primary oxygen supply (shown as a cryogenic generator) is supplemented by a liquid oxygen reserve supply and accompanying vaporizer. With a cryogenic generator, unlike a PSA generator, losses occuring from the liquid oxygen backup tank, either through usage or evaporation, can be replenished directly from the primary supply source.

Oxygen gas from the supply system is pressurized to 30 psig (2.1 kfg/sq cm) with a separate compressor (not shown in Figure 2-3) and fed down through the hollow RAD shafts and then radially outward through small ducts located inside the diffuser plate to the ceramic medium. As oxygen gas emerges from the upper and lower diffusion bands, the rotational shear created by centrifugal force forms ultra small bubbles in the 50-100 micron range which do not coalesce as they move outward and pass over the outside tapered edge of the diffuser plate. The primary function of the tapered edge is to prevent turbulence which could induce bubble coalescence. The resulting micron bubble dispersion resembles a mist from which oxygen is rapidly and efficiently dissolved in the mixed liquor. The oxygen transfer rate obtained with bubbles of this minute size is sufficiently high to reportedly sustain an oxygen utilization efficiency greater than 90 percent in conventional depth uncovered aeration tanks (4).

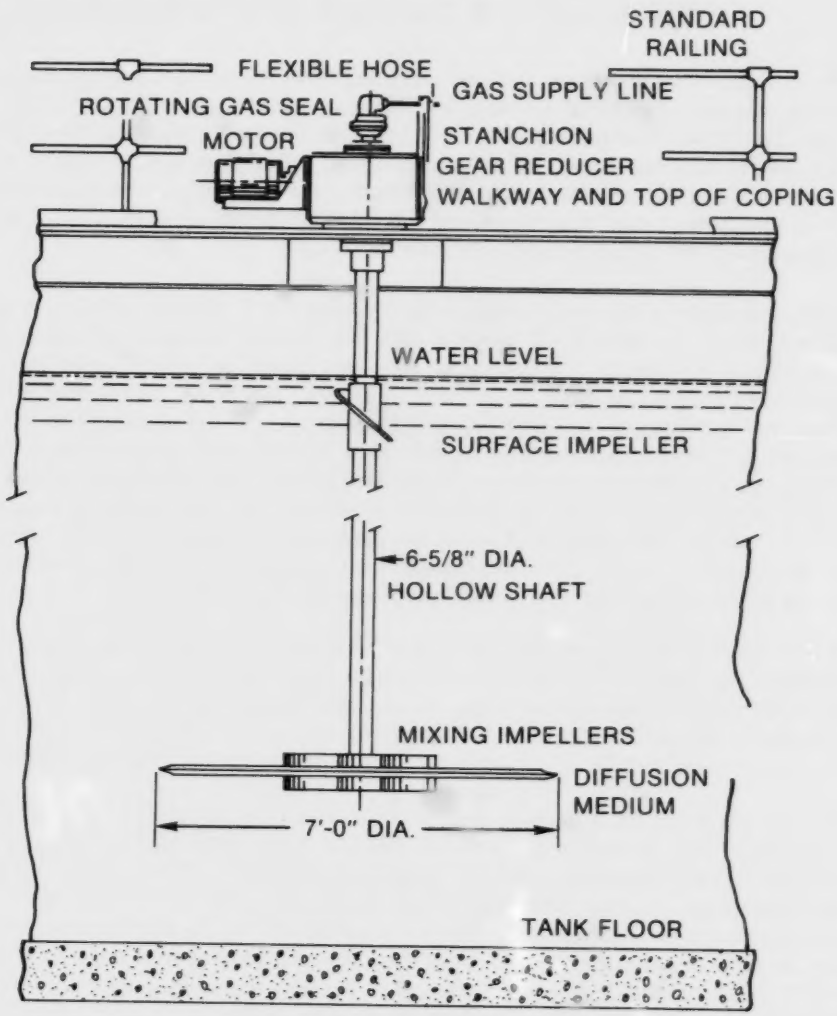

Figure 2-1. Section view of rotating active diffuser and drive assembly

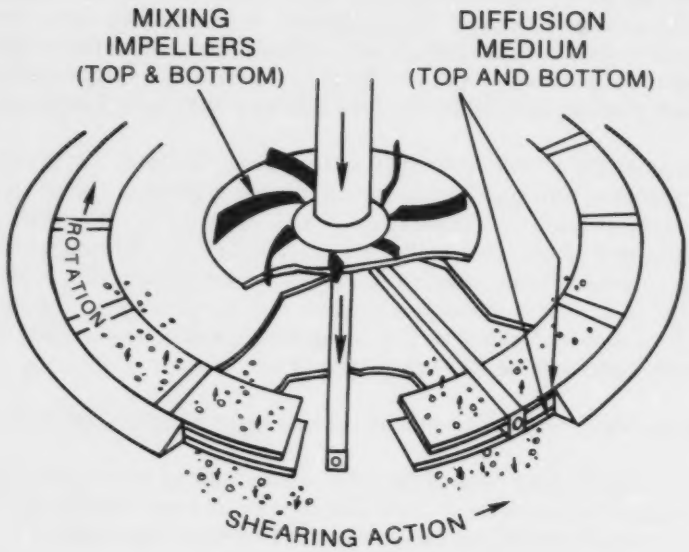

Figure 2-2. Perspective view of submerged rotating active diffuser showing gas flow and bubble formation.

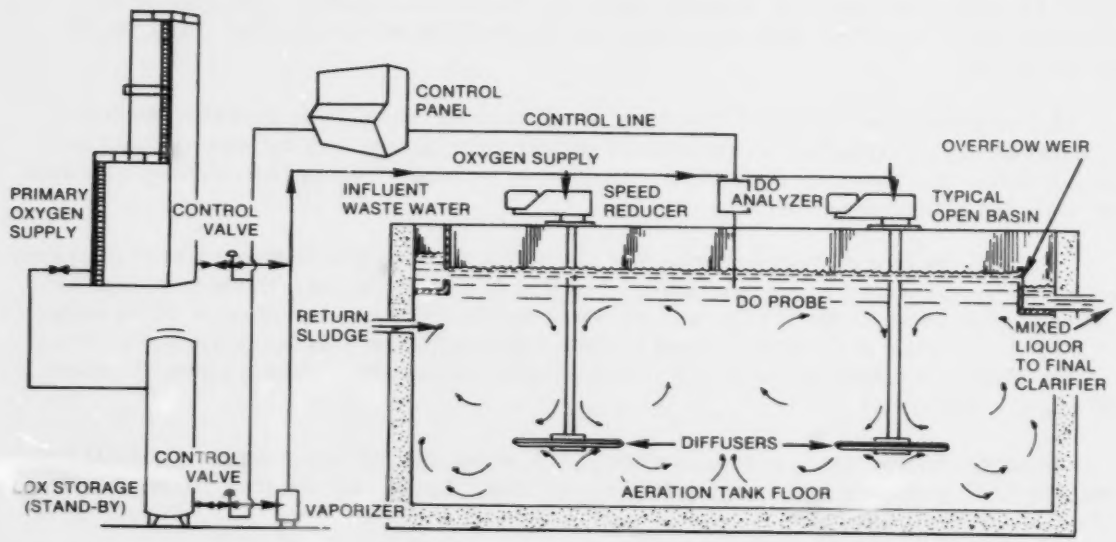

Figure 2-3. Functions flow diagram of typical system employing rotating active diffusers.

A dissolved oxygen (DO) feedback system is used to control the oxygen feed rate to the RAD's. The control system, consisting of one or more DO probes, analyzers, control valves, and electronic controllers, automatically maintains the mixed liquor DO concentration at a predetermined setpoint, within the tolerance range of the equipment. A one-module control system, i.e., one probe, analyzer, control valve, and controller each, is shown controlling the oxygen feed rate to both diffusers in Figure 3. In a longer tank requiring 10-20 RAD's, multiple control modules would be necessary with each module controlling the feed rate to a bank of 3-5 diffusers.

The lack of necessity for a tank cover avoids the sealing problems that must be considered with the covered reactor systems. Although most covered reactor systems designed to date have included staging baffles, they are not essential. Both the open and covered reactor alternatives can be designed compatibly with any of the commonly used activated sludge flow regimes. Covered reactor systems are, however, more naturally adapted to the conventional plug flow regime. Where conventional activated sludge treatment is the flow regime of choice, the staged configuration more nearly approximates ideal plug flow and, other factors being equal, would be expected to deliver an effluent with a slightly lower soluble BOD than an unstaged system.

Other features distinguishing the open and covered reactor approaches from each other are:

1. *The type of oxygen feed control systems.* As mentioned previously, open reactor systems utilize a DO based oxygen feed control system. The covered reactor systems control oxygen feed rate by maintaining a predetermined gas pressure in the first-stage head space.

2. *Freeboard requirements.* Covered reactors require more freeboard than open reactors. The greater freeboard is needed to provide adequate gas space for the umbrella throw pattern of the surface aerators normally employed in covered reactor designs. Utilization of submerged oxygen dissolution equipment obviates the necessity for as large a freeboard with the open reactor system.

3. *Carbon dioxide buildup.* It is anticipated that open reactor systems will be less subject to carbon dioxide buildup and attendant pH depression than systems due to the absence of a tank cover. The degree to which cell respiration by-products are vented from the open reactor will depend primarily on surface turbulence levels and the thickness of foam buildup, if any, on the aerator surface.

4. *Hydrocarbon buildup.* The absence of a tank cover virtually eliminates the possibility of accumulating an explosive concentration of volatile hydrocarbons over the aerator liquid surface. It is assumed, therefore, that safety precautionary measures could be less extensive with open systems than with covered reactor systems.

5. *Oxygen feed pressure to the oxygen dissolution systems.* The nominal pressure of oxygen gas leaving cryogenic and PSA generators is 3-5 psig (0.21-0.35 kgf/sq cm). This is more than sufficient to satisfy line and entrance losses to a covered reactor and maintain a pressure of 1-3 inches (2.5-7.5 cm) of water in the first-stage vapor space. Conversely, head loss through either of the open reactor diffusers is substantial, requiring an additional compressor to pressurize generator output to 30 psig (2.1 kgf/sq cm).

In comparing the two open reactor options, the several inherent advantages of the RAD system over the FAD system are expected to produce a pronounced preference for the RAD alternative. These advantages include:

- no requirement for prescreening of aerator influent,

- no requirement for pumping mixed liquor through the diffusers to create the necessary shear to produce micron size bubbles,

– reduced oxygen dissolution power requirements,

– simplified installation, and

– less maintenance.

METRO DENVER DEMONSTRATION PROJECT

In June 1975, the U.S. Environmental Protection Agency (EPA) awarded a $200,000 demonstration grant to Metropolitan Denver (Colorado) Sewage Disposal District No. 1 to evaluate the MAROX system. The remainder of the estimated total project cost of $605,000 is being shared by the District and FMC. The EPA Grant No. is S803910.

The evaluation is being conducted in a segment of Metro Denver's existing air-activated sludge plant. The plant's secondary system consists of thirty-six 210-ft (64-m) long, 670,000-gal (2536-cu m) aeration bays and twelve 130-ft (39.6-m) diameter clarifiers. Each of the clarifiers is mated with three aeration bays operated in series to form 12 parallel secondary trains. Several of the bays have, on occasion, been utilized for aerobic stabilization of waste activated sludge. Sludge is re-cycled separately for each quadrant of the plant, i.e., settled sludge from the three clarifiers in any given quadrant is transferred to a common collection well from where it is returned for distribution among the three aeration trains in that quadrant.

Approximately two-thirds of the average influent flow of 140 mgd (6.1 cu m/sec) receives primary sedimentation before it reaches the plant; the other third is primary settled on site. A new 72 mgd (3.2 cu m/sec) UNOX facility will divert a significant fraction of the primary effluent flow from the existing overloaded air-activated sludge plant.

Prior to grant award, it was mutually decided that the large-scale MAROX system to be evaluated by the District would employ RAD's rather than the older FAD's used in previous pilot-scale studies at Metro Denver and on a previous EPA supported grant project at the Englewood, Colorado, wastewater treatment plant (2) (3). Thirteen RAD's were installed in the first bay of aeration train No. 11 of the existing Metro air plant. The other two bays of this train have been taken out of service for the duration of the project. Required hydraulic modifcations included the installation of a pipe to transfer mixed liquor from the end of the first bay to clarifier No. 11 and separate return and waste sludge lines and pumps. The latter step was taken to isolate MAROX sludge from the recycle sludge of the two remaining operating air trains (Nos. 7 and 9) of the plant's northeast quadrant. A liquid oxygen storage tank and vaporizer were installed adjacent to the converted oxygen test bay. During the first portion of the evaluation, trucked-in liquid oxygen is being used for oxygen supply. However, the two 40-ton/day (36.3-metric ton&day) cryogenic oxygen gas generators that will serve the new Metro Denver UNOX treatment plant will have excess capacity initially. For economic reasons, consideration is being given to utilizing the excess capacity for supplying oxygen to the demonstration project once shake-down of the cryogenic units is complete. If this action is taken, a compressor will have to be installed to raise generator output pressure to a level compatible with RAD operation. A process schematic of the Metro Denver test system is given in Figure 2-4. Dimensioned plan and section views are shown in Figure 2-5.

As indicated in Figure 2-5, the RAD's are located on 21-ft (6.4-m) centers. Six of the 13 diffusers were installed in sets of two in the first quarter of the tank where oxygen demand is greatest. The remaining seven diffusers are located in tandem on the longitudinal center line of the aeration tank. The first 11 RAD's are driven by 10-hp (7.5-kw) motors and rotate after gear reduction at 85 rpm. The motors for the last two RAD's are 7-1/2 hp-(5.6-kw) units. The rotational speeds of the twelfth and thirteenth RAD's are 80 and 76 rpm, respectively. The oxygen dissolution capa-

bility of the diffusers is rated at 1500 lb/day (680 kg/day) each in the District's wastewater for a total system capacity of 9.75 tons/day (8.85 metric tons/day). Previous proprietary tests indicated these diffusers can be operated up to 33 percent over their rated capacity without significantly affecting oxygen transfer efficiency. On this basis, assuming an average BOD_5 removal of 140 mg/l and an oxygen requirement of 1.3 lb O_2/lb BOD_5 removed (1.3 kg/kg), the maximum sustained flow which can be handled by this oxygen dissolution equipment is roughly 17 mgd (0.74 cu m/sec).

Three DO probes and control systems are employed to control oxygen feed to the Metro Denver test bay. One system controls the feed rate to the first six diffusers, the second to the middle four diffusers, and the third to the last three diffusers. Based on mutual agreement, an initial DO setpoint of 3.0 mg/l was selected. During the first month following startup, the oxygen control equipment exhibited a variance range of ±0.7 mg/l from the desired setpoint.

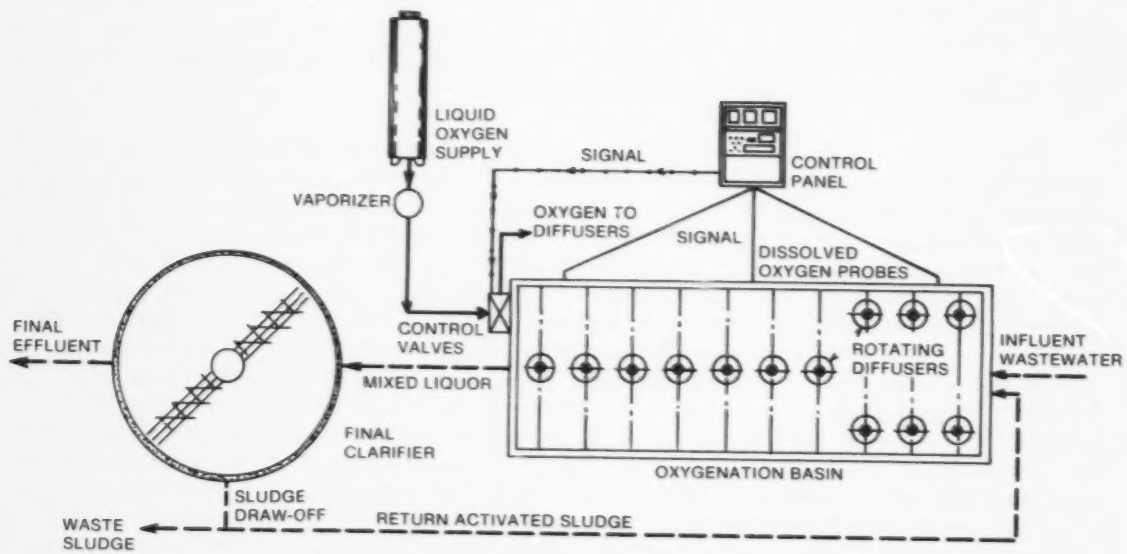

Figure 2-4. Process schematic of Metro Denver test system.

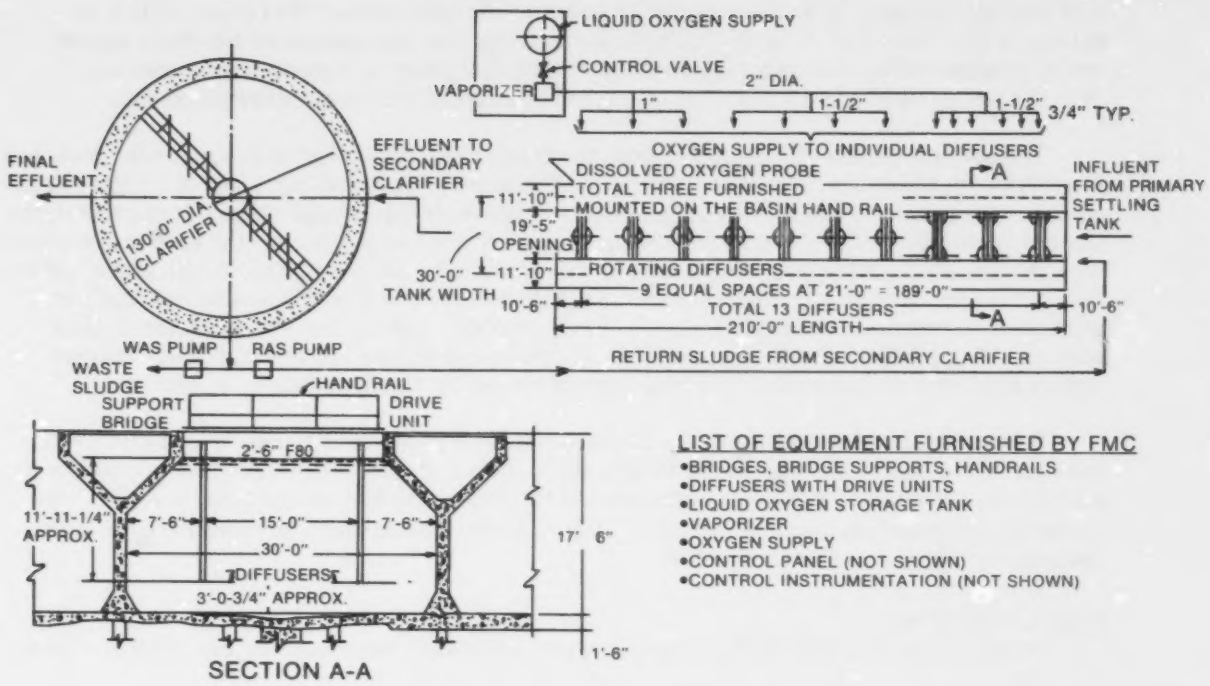

Figure 2-5. Dimensioned plan and section views of Metro Denver test system

The RAD's and RAD drives are supported from metal bridges which span the aeration test bay, as illustrated in Figure 2-5. The bridges in turn are supported by stanchions (not shown in Figure 2-5) running to the tank floor. The bridges were tied with minimal defacing into the side walls of the test bay to prevent lateral movement. Following delivery of the key components of the oxygen supply and dissolution systems to the project site, the entire installation including piping modifications was completed in six weeks. Due in part to the short period in which its system components can be installed and the minimum structural modifications required, the upgrading of existing air-activated sludge plants as exemplified by the Metro Denver demonstration project is expected to become an important application.

From the section view of Figure 2-5, it can be seen that surface impellers were not provided with the RAD's. The District has experienced a float building of relatively high solids concentration (2-3 percent TSS) on the mixed liquor surface. Under other circumstances and with the proper removal equipment, this float would constitute a potentially attractive source from which to waste excess sludge at a substantially higher solids concentration than available in secondary clarifier underflow. Since the District is not equipped to waste sludge in this manner, the presence of the float represents an operational and esthetic liability. To overcome this problem, installation of an aeration test bay overflow weir, similar to the one shown in Figure 2-3, is under consideration. The weir would replace the present submerged orifice through which the mixed liquor now exits the aeration bay. Utilization of an overflow weir would promote continuous transfer of floated solids to the secondary clarifier before they could accumulate on the liquid surface. Another float avoidance technique being evaluated is the use of one or more down draft propeller pumps to recirculate floated solids back into the mixed liquor. For long term operation, the overflow

weir option is believed to be a more positive and cost-effective method than either surface impellers on the RAD shifts or down draft propeller pumps. For expediency on this finite length demonstration project, however, the down draft propeller pump technique may be selected, even though it would add 6-12 percent to oxygen dissolution system power requirements.

The major objective of the project from the District's standpoint is to determine the technical feasibility and attendant costs of converting its existing air-activated sludge plant to a higher capacity (i.e., two to three times higher) open reactor, oxygen-activated sludge system. If successful, the District could potentially avert another major secondary plant expansion for the foreseeable future, with the exception of the additional clarifiers which would be needed to handle increases in influent flow. EPA's primary project objectives are: (1) to demonstrate at a representative field scale an alternative oxygenation concept which has been extensively and successfully evaluated at pilot scale and (2) to define reliable design criteria, operating conditions and costs, and performance expectation for a system embodying that concept for use by the engineering community.

Equipment installation and piping modifications were completed in early May 1976. The remainder of the month was devoted to facility shakedown and adjustments. June was utilized as a process start-up period for training operators and refining a data logging and retrival system. The evaluation program was initiated on July 1, 1976. The five phases and corresponding dates of the evaluation program are described below:

Phase I, July 1976,
Constant flow @ 2 mgd (0.39 cu m/sec); warm wastewater temperatures; one clarifier only in use

Phase II, August-September 1976,
Diurnally varied flow @ 7 to 14 mgd (0.31 to 0.61 cu m/sec); warm wastewater temperatures; second clarifier available, if necessary

Phase III, October 1976,
Constant flow @ 2 mgd (0.34 cu m/sec); cool wastewater temperatures; one clarifier only in use

Phase IV, November-December 1976,
Diurnally varied flow @ 7 to 14 mgd (0.31 to 0.61 cu m/sec); cool wastewater temperatures; second clarifier available, if necessary

Phase V, January-April 1977,
Constant flow increased in increments to failure; cool wastewater temperatures; two clarifiers in use

Anticipated operating conditions are not documented here for each planned phase because of the variability that will be introduced by diurnal flow. However, for reference purposes, baseline operating conditions are summarized below for the 9-mgd (0.4 cu m/sec) constant flow phases, assuming an average primary effluent BOD_5 concentration of 140 mg/l, a sludge return rate equal to 40 percent of the influent flow rate, and average mixed liquor suspended solids (MLSS) and mixed liquor voltaile suspended solids (MLVSS) concentrations of 4000 and 3200 mg/l, respectively:

Nominal Aeration Time (based on Q) = 1.79 hr
Actual Aeration Time (based on Q + R) = 1.28 hr
Food to Microorganism (F/M) Loading = 0.59 lb BOD_5 applied/day/lb MLVSS under aeration (0.59 kg/day/kg)
Volumetric Organic Loading = 117 lb BOD_5 applied/day/1000 cu ft aerator volume (1503 kg/day/cu m)

Secondary Clarifier Overflow Rate (based on total surface area) = 678 gpd/sq ft (27.6 cu m/day/sq m)
Secondary Clarifier Overflow Rate (based on useful surface area; excludes effluent launder area) = 746 gpd/sq ft (30.4 cu m/day/sq m)
Secondary Clarifier Mass Loading (based on floor area) = 31.7 lb MLSS/day/sq ft (155 kg/day/sq m)

Average operating and performance data for the startup month of June 1976 are presented in Table 9. The average secondary effluent suspended solids (TSS) concentration of 30 mg/1 is only marginally acceptable. Daily log sheets reveal, however, that this effluent parameter exhibited a steadily decreasing concentration trend throughout the 30-day period as operators became more familiar with system operation and sludge inventory management. Effluent TSS for the first 12 days of July averaged 20 mg/1, a 33 percent decrease from June. The seven-day/week data collection program depicted in Table 2-1 will be used, along with several additional tests not conducted in the startup month, throughout the planned evaluation studies. One of these additional tests will be the periodic determination of oxygen utilization efficiency. This will be accomplished with the aid of a 6-ft x 6-ft (1.8-m x 1.8-m) floating dome. Off gases from a 36-sq ft (3.34-sq m) area of tank surface will be collected inside the dome and funneled through a gas flow and composition monitoring station. The tent will be moved to different sections of the aeration test bay to arrive at a composite or average utilization efficiency.

Caution should be exercised in extrapolating the sludge production and oxygen supply rates given in Table 2-1. These values are for one month of operation only and were generated immediately following a period of operator familiarization with a new process. A better perspective of the relationship of these important parameters to organic loading will be gained from an evaluation of all the data at the end of the project.

Table 2-1. ***June 1976 Average Operating and Performance Data for Metro Denver Open Reactor Oxygenation Project***

Influent Flow	9.5 mgd
Return Sludge Flow	3.8 mgd
Return Sludge Flow/Influent Flow	40%
Pri. Eff. BOD_5	126 mg/1
Sec. Eff. BOD_5	19 mg/1
BOD_5 Removed Across Secondary	85%
Pri. Eff. TOC	87 mg/1
Sec. Eff. TOC	29 mg/1
TOC Removed Across Secondary	67%
Pri. Eff. TSS	88 mg/1
Sec. Eff. TSS	30 mg/1
TSS Removed Across Secondary	66%
MLSS	3050 mg/1
MLVSS	2610 mg/1 (volatiile fraction = 85.6%)
Mixed Liquor DO	2.7 mg/1
Mixed Liquor Temperature	20° C
Return Sludge TSS	10,970 mg/1
Return Sludge VSS	9120 mg/1 (volatile fraction = 83.1%)
Depth to Clarifier Sludge Blanket	7.5 ft
Nominal Aeration Time (based on Q)	1.69 hr
Actual Aeration Time (based on Q + R)	1.21 hr
F/M Loading	0.68 lb BOD_5 applied/day/lb MLVSS under aeration
Volumetric Organic Loading	111 lb BOD_5 applied/day/1000 cu ft aerator volume
Secondary Clarifier Overflow Rate (based on total surface area)	716 gpd/sq ft
Secondary Clarifier Overflow Rate (based on useful surface area; excludes effluent launder area)	787 gpd/sq ft
Secondary Clarifier Mass Loading (based on floor area)	25.5 lb MLSS/day/sq ft
Waste Activated Sludge Mass	5060 lb/day
Sludge Production Rate (based on waste sludge TSS only)	0.60 lb TSS/lb BOD_5 removed
Sludge Production Rate (based on waste sludge & sec. eff. TSS)	0.88 lb TSS/lb BOD_5 removed
Sludge Retention Time (SRT)	2.3 lb MLSS under aeration/ (lb waste sludge TSS + sec. eff. TSS lost)/day = 2.3 days
RAD Power Draw	109 hp
Oxygen Supplied	11,363 lb O_2/day
Oxygen Supply Rate (based on load)	1.14 lb O_2/lb BOD_5 applied
Oxygen Supply Rate (based on removal)	1.34 lb O_2/lb BOD_5 removed

Chapter 3

CASE HISTORIES

Operating and performance data and case history summaries are presented below for 11 oxygen-activated sludge plants. All 11 plants are documented in the listing of operating facilities provided in Table 1-1.

The case histories were selected to illustrate a variety of process applications, system component configurations, and plant sizes. Eight of the selected plants treat municipal wastewaters: three are strictly industrial applications. Several of the municipal installations receive a significant fraction of their incoming loads from industrial sources. The reactor designs for these plants represent a variety of configurations including both rectangular-stage systems and systems incorporating circular and arcuate stages within larger self-contained circular tanks.

In addition to operating and performance data, a flow diagram is presented for each case history along with pertinent background information, where known, leading to the selection of an oxygen system.

Noteworthy start-up, operating, and maintenance difficulties encountered are discussed. Secondary system components and any flow routing peculiarities are described briefly. Data available to the writer for summarization herein varied from one month's results at several plants to more than two years' results at another location.

Decatur, Illinois

Prior to the recent addition of a UNOX system, the Sanitary District of Decatur's wastewater treatment plant consisted of two rectangular primary clarifiers, six Imhoff tanks, 12 air aeration days, three secondary clarifiers, two trickling filters, one primary anaerobic digester, one secondary digester, one supernatant holding tank, and tertiary and sludge lagoons. Six of the existing air aeration bays are of 1935 vintage; the other six are larger and were installed in 1965.

In July 1975, the liquid portion of a comprehensive plant upgrading program was completed. The heart of this upgrading effort was the conversion of three of the 1965 air aeration bays to oxygen service. The walls of these bays were extended upwards 4 ft (1.2 m) and the bays covered to provide the needed vapor space to satisfactorily control oxygen feed and interstage gas transport. The remaining nine air aeration bays have been combined into an integrated system to operate in parallel with the oxygen unit in either the conventional mode or as a modified contact stabilization process. The nine bays are shown schematically in the flow diagram of Figure 3-1 as two tanks, one representing the six older 1935 bays, the other the three newer 1965 bays.

Coinciding with the modifications to implement oxygen-activated sludge treatment, three new primary clarifiers and four new secondary clarifiers were constructed. Two of the three new primaries have 100-ft (30.5-m) diameters and are in use continuously. The third new primary has a diameter of 130 ft (39.6 m) and is only used during severe storms with the overflow discharged directly to the receiving river following chlorination. The new secondary clarifiers are mated with the UNOX system, the old secondaries with the revamped air aeration facilities. The diameter and

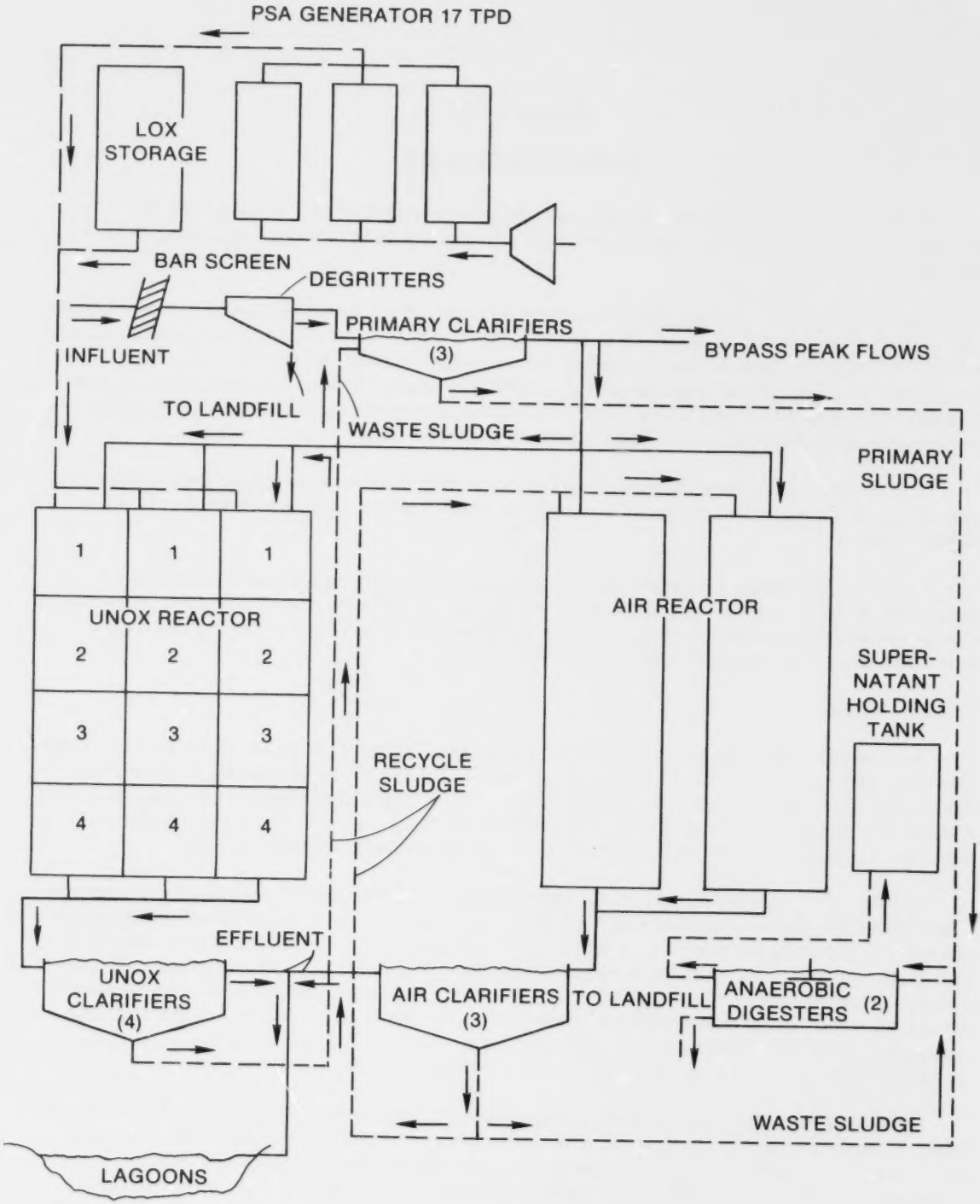

Figure 3-1. Flow diagram of Decatur, Illinois wastewater treatment plant.

side water depth (SWD) of the new secondaries are 100 ft (30.5 m) and 12.5 ft (3.8 m), respectively. The old trickling filters (not shown in Figure 3-1) were abandoned in September 1975. The old rectangular primary clarifiers (also not shown in Figure 3-1) have been placed on standby service.

A program to upgrade the sludge handling portion of the plant was completed in December 1976. The old supernatant holding tank and old secondary digester were converted to heated primary anaerobic digesters to join the one existing primary digester. Supernatant is now returned directly to the plant headworks. Five of the existing six Imhoff tanks (omitted from Figure 3-1) were outfitted with covers to operate as non-heated secondary digesters. The sixth Imhoff tank remains uncovered and serves as a holding tank for both oxygen and air waste activated sludges prior to separate thickening in a new concentrator. Waste sludge was returned to the primaries for thickening before digestion.

Each of the three oxygen trains is divided into four stages. The overall dimensions of the oxygen reactor are 148 ft long x 77 ft wide x 14 ft SWD (45 m x 23.5 m x 4.3 m) with a freeboard of 4 ft (1.2 m). The oxygen dissolution system consists of surface aerators combined with bottom propellers for additional mixing. The PSA oxygen generation unit has a design output capacity of 17 tons/day (15.4 metric tons/day). The storage capacity of the backup liquid oxygen supply tank is 43 tons (39 metric tons).

On the average, 55 to 60 percent of the incoming organic load is from industrial sources, primarily corn and soybean processing. Some of the industrial contributors have their own treatment facilities which discharge effluent into the Decatur sewer system. The particular mixture of domestic, industrial, and partially treated wastes received at the Decatur plant is conducive to the formation of a poor settling filamentous sludge. Filamentous conditions have been a historical problem with and continue to seriously plague the air aerated trains. According to plant personnel, filamentous infestation is much less prevalent in the oxygen sludge, but is present in sufficient quantities that a substantially less dense settled sludge is produced than predicted. Even so, oxygen clarifier underflow concentrations range from 70-100 percent higher than comparable data for settled air sludge.

The inability to thicken oxygen sludge during clarification to the degree planned has resulted in lower MLSS and higher F/M operating conditions than designed for. These conditions have apparently not adversely affected effluent quality which remained good throughout the first year of operation, as indicated in Table 3-1. The somewhat higher effluent suspended solids value shown for February corresponded to an average influent flow equal to 115 percent of design. The effluent data given in Table 3-1 represented UNOX system effluent quality prior to mixing with air system effluent or subsequent treatment in the tertiary lagoons.

Recent communication with the assistant plant manager elicited the following observations on his part:

1. The oxygen system has consistently outperformed the air system by a wide margin, despite treating approximately twice as much flow in a substantially smaller reactor volume.

2. The oxygen system has exhibited excellent day-to-day process reliability and is generally capable of recovering from slug loading upsets within 24 hours.

3. Oxygen dissolution and supply systems require more operator attention than conventional air processes, primarily because of the greater amount of instrumentation involved. Several equipment malfunctions to date have been beyond the ability of the plant operating staff to correct and have required attention on the part of the vendor.

4. Several PSA compressor outages are experienced during early operations due to an improper inner cooling system. The cooling system was eventually redesigned and rebuilt and is now performing satisfactorily.

The upgrading modifications implemented at Decatur have resulted in an increase in plant capacity from 20 mgd (0.9 cu m/sec) to 25 mgd (1.1 cu m/sec) and a substantial improvement in total plant performance. Two-thirds of the upgraded 25 mgd (1.1 cu m/sec) capacity is assigned to the new oxygen system, one-third to the existing air system.

Table 3-1. ***Operating and Performance Data for Decatur, Illinois Oxygen System***

Parameter	Design	Operation		
		Aug. 1975	Feb. 1976	July 1976
Influent Flow (mgd)	17.7	14.4	20.4	14.1
Aeration Detention Time, Q (hr)	1.6	1.97	1.39	2.01
F/M Loading (kg BOD_5/day/kg MLVSS)	0.62	1.10	1.47	0.91
Secondary Clarifier Overflow Rate (gpd/sq ft)	560	456	645	446
MLSS (mg/1)	5500	2700	3300	2600
Return Sludge TSS (%)	1.9	0.55	0.93	0.87
Reactor Influent BOD_5 (mg/1)	188	157	129	98
TSS (mg/1)	138	139	138	99
Secondary Effluent BOD_5 (mg/1)	20	9	15	10
TSS (mg/1)	25	22	36	20

Detroit (#1), Michigan

Initial planning for expansion to secondary treatment at Detroit called for the installation of a 1200 mgd (52.6 cu m/sec) air-activated sludge facility to be completed over a four-phase construction period spanning approximately ten years. Two 150-mgd (6.6-cu m/sec) air train modules were to be installed during each construction phase, yielding an eventual total of eight modules.

Coinciding with Detroit's planning program, the use of oxygen in the activated sludge process was being investigated in a federally supported research project at Batavia, New York (1) (2) (3). Based primarily on promising results emanating from this project, Detroit became interested in utilizing oxygen in its own treatment situation. The City made a decision in 1969 to modify its first construction phase to include one 150-mgd (6.6-cu m/sec) air module and one 300-mgd (13.1-cu m/sec) UNOX module. The reactor tanks for both systems were designed with identical outside dimensions, meaning that the aeration detention time of the oxygen system was to be one-half of that of the air system. The high-rate treatment potential of the oxygenation process was of utmost importance to the City because of a serious land shortage problem.

The construction contract awarded by the City included process guarantee requirements for the system in the areas of effluent quality, power consumption, and oxygen consumption. The efficacy of the UNOX and air systems was to be compared in parallel test runs. Depending on the results of the tests, the two systems were designed such that the 150-mgd (6.6-cu m/sec) air train could be readily converted to a 300-mgd (13.1-cu m/sec) oxygen train by the addition of a tank cover, submerged turbine/sparger units for oxygen dissolution, and three more secondary clarifiers. With this possibility in mind, the compressors which continuously recirculate gas through the sub-

merged turbine/sparger units were double sized to handle 600 mgd (26.3 cu m/sec). If the test results indicated superior performance by the air train, the City retained the option by virtue of the identical reactor designs of switching the higher capacity oxygen system to a 150-mgd (6.6-cu m/sec) air system by removing the tank cover and substituting air draft tubes for the oxygen dissolution equipment.

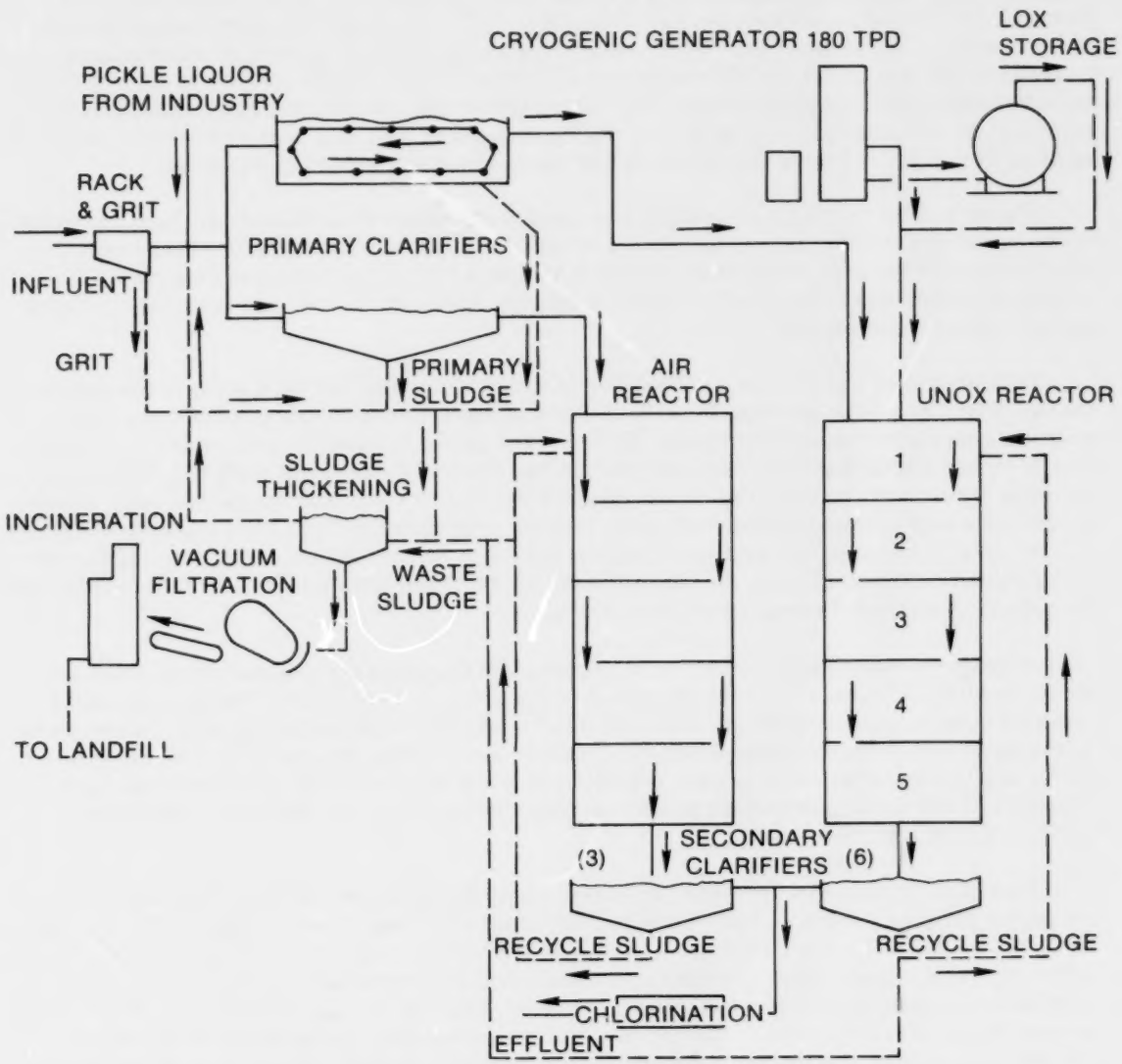

Figure 3-2. Flow diagram of Detroit, Michigan wastewater treatment plant - Phase #1 construction.

For the test runs, six secondary clarifiers were to be mated with the oxygen reactor, three with the air reactor. The clarifiers are of unique design with a diameter of 200 ft (61 m), a SWD of 16 ft (4.9 m), an extremely high average surface overflow rate of 1600 gpd/sq ft (65 cu m/day/sq m), rapid sludge removal suction pipes, and a peripheral-feed rim-takeoff flow configuration. Although the oxygen module has been in operation since August 1974, the writer is not aware of the publication of any officially conducted comparative test results on the two systems to date. Normal start-up problems and delays in getting nine clarifiers completed reportedly contributed to the delay in parallel testing. Whether official test data are eventually published or not, it would appear that Detroit is committed to oxygen use. Two new 300-mgd (13.1-cu m/sec) oxygen modules are now under construction as part of the City's second-phase construction program. The second-phase oxygen systems will utilize OASES equipment. If Detroit decides at a future date to convert the air train installed under first-phase construction to oxygen service, the City will have realized its ultimate goal of 1200 mgd (52.6 cu m/sec) of treatment capacity with four reactor modules instead of eight. A flow diagram for the first-phase air and oxygen modules is given in Figure 3-2.

The large 30-ft (9.1-m) reactor SWD employed in first-phase construction necessitated the use of the submerged turbine oxygen dissolution alternative. The overall dimensions of the reactor are 600 ft long x 140 ft wide x 33 ft deep (183 m x 42.7 m x 10.1 m). Oxygen gas is supplied by a 180-ton/day (163-metric ton/day) cryogenic generator. A 900-ton (816-metric ton) liquid oxygen storage tank provides backup.

Following start-up, it became evident that sufficient detail had not been given to the design of the submerged turbine assemblies. Propeller failures and gear box problems resulted from inadequate materials selection and fabrication. Redesign and partial equipment replacement were necessary to correct the deficiencies. Another problem encountered by the plant staff was obtaining a tight seal at the joints between the outside edges of the reactor cover and the reactor walls. Despite experiments with several different sealants and sealing procedures, this situation was only marginally rectified at the time of this writing. Cryogenic generator performance has been very satisfactory with minimal downtime. During the first 550 days of operation, less than 2.5 percent scheduled and 0.4 percent unscheduled outages were experienced.

Average operating and performance data for the UNOX system are documented in Table 3-2 for September 1975 and a 1-1/2 month period in the spring of 1976. These data were generated at constant influent flow. Imposition of diurnal flow variations will be postponed until the remainder of the secondary treatment trains under construction come on-line. It is obvious that reactor influent BOD_5 concentrations have been considerably lower than expected. The weaker strength primary effluent is partially attributable to the recent initiation of iron addition to the primary clarifiers for phophorus removal.

Two major operational problems have surfaces with the secondary clarifiers. One involves achieving proper peripheral influent distribution to avoid short circuiting of mixed liquor solids directly up to the rim-takeoff weirs. The other is the extreme difficulty encountered in getting settled sludge to thicken to acceptable concentrations prior to removal from the clarifiers. The impact of the thin settled sludge situation is evident in Table 3-2 in low MLSS levels and high F/M loadings. The Detroit oxygen sludge does have good thickening properties as exemplified by the ability to separately thicken waste sludge to 4 percent solids in 24 hours without chemical conditioners. In the writer's opinion, secondary clarifier operational difficulties will continue as long as the clarifiers are subjected to the inordinately high overflow rates currently in use.

Table 3-2. Operating and Performance Data for Detroit (#1), Michigan Oxygen System

Parameter	Design	Operation	
		1975	March 29 — May 9, 1976
Influent Flow (mgd)	300	302	299
Aeration Detention Time, Q (hr)	1.42	1.41	1.42
F/M Loading (kg BOD_5/day/kg MLVSS)	0.47	0.58	1.05
Secondary Clarified Overflow Rate (gpd/sq ft)	1600	1611	1595
MLSS (mg/1)	6250	2340	2750
Return Sludge TSS (%)	--	0.66	0.85
Reactor Influent BOD_5 (mg/1)	140	44	101
TSS (mg/1)	150	105	240
Secondary Effluent BOD_5 (mg/1)	25	6	17
TSS (mg/1)	30	9	31

Fairfax County, Virginia

The Westgate plant is one of four municipal wastewater treatment plants operated by Fairfax County,Virginia. This plant, constructed in 1954, was originally designed to remove 50 percent of the BOD_5 loading from a design flow of 8 mgd (0.35 cu m/sec).

Basic features of the original Westgate facility in sequence consisted of bar screening, comminution, primary clarification, once-through aeration, secondary clarification, and chlorination. Sludge recycle pumps were not provided. The main treatment basin was divided into two parallel tanks. Each tank housed primary clarification, aeration and secondary clarification sections separated only by baffles. Scraper chains passed along the entire floor length through all the sections of the tanks. The apparent purpose of the scrapers was to move biological solids and grit settling out in the secondary clarification zones back to the primary clarification zones where they could be removed from the system. Although the original plant was not intended to function as an activated sludge system, it is highly likely that some settled solids were resuspended in the aeration zones during scraping transport, thus maintaining a small active biomass population in those zones. The decision to forego installation of the additional clarifier appurtenances, sludge recycle equipment, and piping which would have permitted operation in a conventional activated sludge mode was necessitated by funding limitations at the time of initial construction.

From 1954 to 1965, plant influent flows increased gradually from 8 mgd (0.35 cu m/sec) to slightly less than 10 mgd (0.44 cu m/sec). BOD_5 and suspended solids removals during this period averaged approximately 50 and 65 percent, respectively. By 1970 with plant flows having further increased to approximately 11 mgd (0.48 cu m/sec), BOD_5 removal had dropped to 45 percent and suspended solids removal to 55 percent. In 1970, faced with the choice of either upgrading BOD_5 removal efficiency to 80 percent or having a building moratorium placed on the area served by the plant, the County submitted a report to the State of Virginia recommending that interim upgrading steps be applied at Westgate pending completion of an expansion program at the nearby Alexandria, Virginia plant. At that time, the Westgate facility would cease operations in favor of flow diversion to Alexandria.

The first interim upgrading approach tried was the addition of ferric chloride to the influent wastewater at the plant headworks followed by anionic polyelectrolyte addition to the aeration zones. This technique yielded an average BOD_5 removal of 71 percent from July 1970 through October 1971, somewhat short of 80 percent removal target. The sludge resulting from chemical addition proved to be more difficult to dewater than that of the original plant.

Laboratory tests indicated that combining powdered activated carbon dosing to the influent wastewater with the above iron and polyelectrolyte additions could potentially improve BOD_5 removal to 75 percent. Full-scale trials with carbon dosing were abandoned in July 1971 after a short-term run due to erosion and feed control problems. Data generated during the run were inconclusive.

During the latter portion of 1970, the County and its engineering consultant concluded that 80 percent interim BOD_5 removal could be achieved more cost effectively with a biological treatment system than with a combination of chemical addition procedures. A decision was then made following technical deliberations to implement biological treatment with an oxygen-activated sludge process rather than a high-rate air-activated sludge process because of reliability and cost considerations. A contract was awarded in the spring of 1971 to convert the existing Westgate plant to an OASES system. A contract period of 210 days was allowed to complete the job.

The upgrading plan developed by the County's engineer consisted of four principal steps:

1. Conversion of the aeration and secondary clarification sections of the existing tanks into a two-train oxygenation reactor leaving the primary clarification sections intact.

2. Installation of two new secondary clarifiers, each 120 ft (36.6 m) in diameter with a SWD of 11 ft (3.4 m) and suction lift scraper arms for removing sludge.

3. Installation of waste activated sludge thickening capability in the form of two flotation thickeners, each having a surface area of 250 sq ft (23.2 sq m).

4. Installation of two 7-mgd (0.31-c m/sec) sludge recycle pumps and separate sludge wasting pumps.

A longitudinal section view of the existing Westgate treatment basin prior to conversion to an oxygen system is given in Figure 3-3. Some of the modifications required to effect the conversion are noted. These included removal of the air diffusers and downcomer piping, removal of the baffles between the old aeration and secondary clarification sections, removal of all old effluent weir sections within the secondary clarification sections proper, removal of the old sludge scrapers from the aeration and secondary clarification zones, replacment of the baffles separating the primary clarification and original aeration zones, and relocation of some sludge scraper sprockets to the primary clarification sections. The converted oxygen reactor was divided into four stages in each train. The stages comprised in order 22, 44, 23, and 11 percent of the total reactor volume. Only the first three stages were covered, the last stage being left open to the atmosphere because of the low oxygen demand which would exist at that point. The gas-tight tank covers and liquid staging baffles were fabricated from carbon steel and coated with an epoxy-phenolic resin. The overall dimensions of the converted oxygen reactor are 138 ft long x 82 ft wide x 12 ft SWD (42 m x 25 m x 3.7 m).

A total of 36 surface aerators with bottom impellers were installed for oxygen dissolution and mixing. Eight of the aerators (utilized at the front end of the reactor) are 10-hp (7.5-kw) units; the other 28 have 5-hp (3.7-kw) drives, yielding a total installed nameplate power load of 220 hp (164 kw). Liquid oxygen is stored on-site and vaporized preceding introduction to the oxygenation system.

Plant modifications were completed and the converted system started up in November 1971, making Westgate the oldest full-scale oxygen-activated sludge facility in the world.

A flow diagram of the modified plant is shown in Figure 3-4. Operation of the new flotation thickeners was terminated after several months. It was found that thickening of excess activated

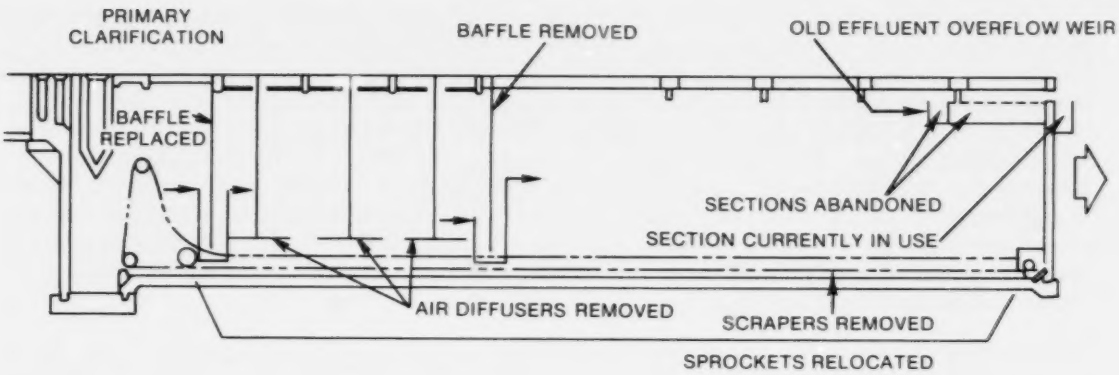

Figure 3-3. Longitudinal sectional view of pre-modified concrete tank at Fairfax County (Westgate), Virginia wastewater treatment plant.

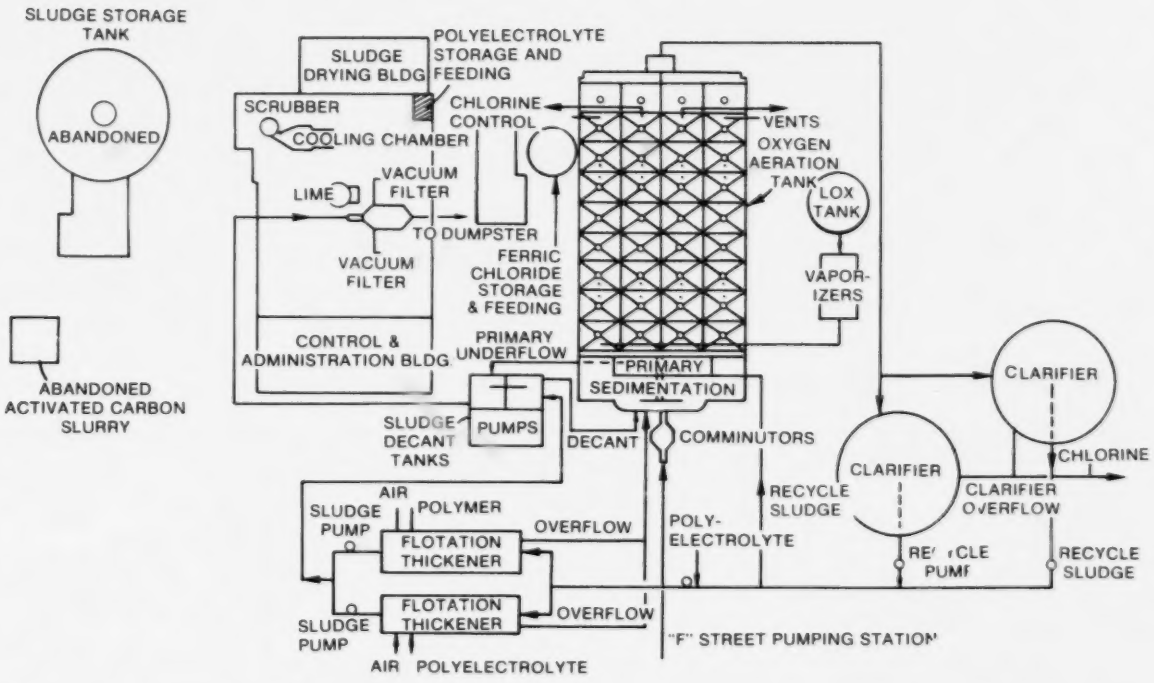

Figure 3-4. Flow diagram of Fairfax County (Westgate), Virginia wastewater treatment plant.

sludge beyond that afforded by gravity decant tanks was not needed prior to mixing with primary sludge and vacuum filtration. The comminutor was also removed from service several months into the upgraded operation.

Start-up difficulties were minimal and of the type normally associated with "debugging" a new system. A process optimization program was undertaken for the County by Air Products and Chemicals from late January 1972 to May 1972. The primary purpose of the program was to define the operating conditions for this first-of-a-kind system which would result in a consistently high level of plant performance. Operating and performance data are presented in Table 3-3 for the one-year period of August 1972 through July 1973. As indicated, excellent effluent quality was achieved, far exceeding the 80 percent BOD_5 removal design specification, at an average influent flow equal to 76 percent of design capacity. Primary influent rather than reactor influent concentrations are included in Table 3-3 because representative sampling of primary effluent is not possible. Little alteration of influent wastewater characteristics is believed to be effected by the primaries due to their short detention time (20-25 minutes).

The Westgate story is a superb example of utilizing existing tankage to the fullest in an upgrading project intended to simultaneously improve plant performance and increase plant capacity. It is not known in view of the excellent performance achieved to date whether the upgraded plant will still be abandoned when the Alexandria expansion is completed or not. The total cost of the Westgate upgrading was $1,672,000, of which $861,000 was expended for the oxygen dissolution and supply systems and reactor tank modifications.

Table 3-3. ***Operating and Performance Data for Fairfax County, Virginia Oxygen System***

Parameter	Design	Operation Aug. 1972 — July 1973
Influent Flow (mgd)	14	10.6
Aeration Detention Time, Q (hr)	1.74	2.3
F/M Loading (kg BOD_5/day/kg MLVSS)	--	0.54§
Secondary Clarifier Overflow Rate (gpd/sq ft)	620	469
MLSS (mg/1)	--	4480
Return Sludge TSS (%)	--	1.87
Primary Influent BOD_5 (mg/1) ‡	220	161
TSS	173	162
Secondary Effluent BOD_5 (mg/1)	44	12
TSS	--	19

‡Not possible to sample reactor influent as only a baffle separates primary clarifier from reactor

§Based on primary influent BOD_5 rather than reactor influent BOD_5; indicated value is, therefore, about 10 percent high.

Gulf States Paper Corporation, Tuscaloosa, Alabama

A custom-designed, self-contained, circular UNOX system was installed at the Gulf States Paper Corporation complex in Tuscaloosa, Alabama, to treat 9 mgd (0.39 cu m/sec) of unbleached kraft mill wastewater. This type of wastewater is deficient in nitrogen and phosphorus. To overcome these deficiencies at Gulf States, phosphoric acid and anhydrous ammonia are added to the primary effluent.

A custom-designed circular UNOX system differs from one of Union Carbide's modular package oxygen plants in that it is not a standard off-the-shelf unit. The Gulf States oxygen system is composed of three above-ground steel tanks each with a diameter of 109 ft (33.2 m), a total depth of 20 ft (6.1 m), and a SWD of 16 ft (4.9 m). Each tank is divided into a four-stage oxygenation reactor and an arcuate clarifier. Three of the four stages are also arcuate; one is circular. Air-lift suction pickups are used to withdraw settled sludge from the clarifiers. Oxygen dissolution and solids mixing are accomplished with surface aerators and bottom propellers. A four-bed 30-ton/day (27.2-metric ton/day) PSA oxygen gas generator and a 43-ton (39-metric ton) liquid oxygen backup storage tank and atmospheric vaporizer comprise the oxygen supply system.

As shown in the flow diagram presented in Figure 3-5, alum can be dosed to a separate polishing clarifier following secondary clarification for the purpose of effecting additional color removal. This color removal system has not been used to any great extent to date, however, because of problems with the alum recovery equipment.

The oxygen system itself has been in operation since October 1974. Following start-up and "debugging," maintenance requirements have been of a routine nature. Operator attention on the unit ranges from 7-10 hr/week.

Operating and performance data for the months of April and May 1975 are summarized in Table 3-4. Although the system is operating at design flow, reactor influent strength has been averaging only about 60 percent of design expectations. It has, therefore, not been necessary to operate at as high MLSS levels as projected to maintain reasonable F/M loadings. The effluent values shown represent product quality from the secondary clarifiers. Additional suspended solids removal is reportedly achieved in passage through the polishing clarifier (operated without alum addition). No data were available to the writer to document the improvement obtained in the polishing clarifier.

Approximately one-half of the PSA generator output is used in the activated sludge system; the other half is utilized for black liquor oxidation. Because of the dual role served by the oxygen supply facilities, the PSA unit was designed to produce 95 percent purity oxygen gas rather than the standard 90 percent product purity normally associated with PSA operation.

Table 3-4. ***Operating and Performance Data for Gulf States Paper Oxygen System***

Parameter	Design	Operation Apr. - May 1975
Influent Flow (mgd)	9.0	9.0
Aeration Detention Time, Q (hr)	3.33	3.33
F/M Loading (kg BOD_5/day/kg MLVSS)	0.36	0.37
Secondary Clarifier Overflow Rate (gpd/sq ft)	630	630
MLSS (mg/1)	4700	3000
Return Sludge TSS (%)	1.9	1.2
Reactor Influent BOD_5 (mg/1)	200	125
TSS	100	60
Secondary Effluent BOD_5 (mg/1)	30	12
TSS	50	50

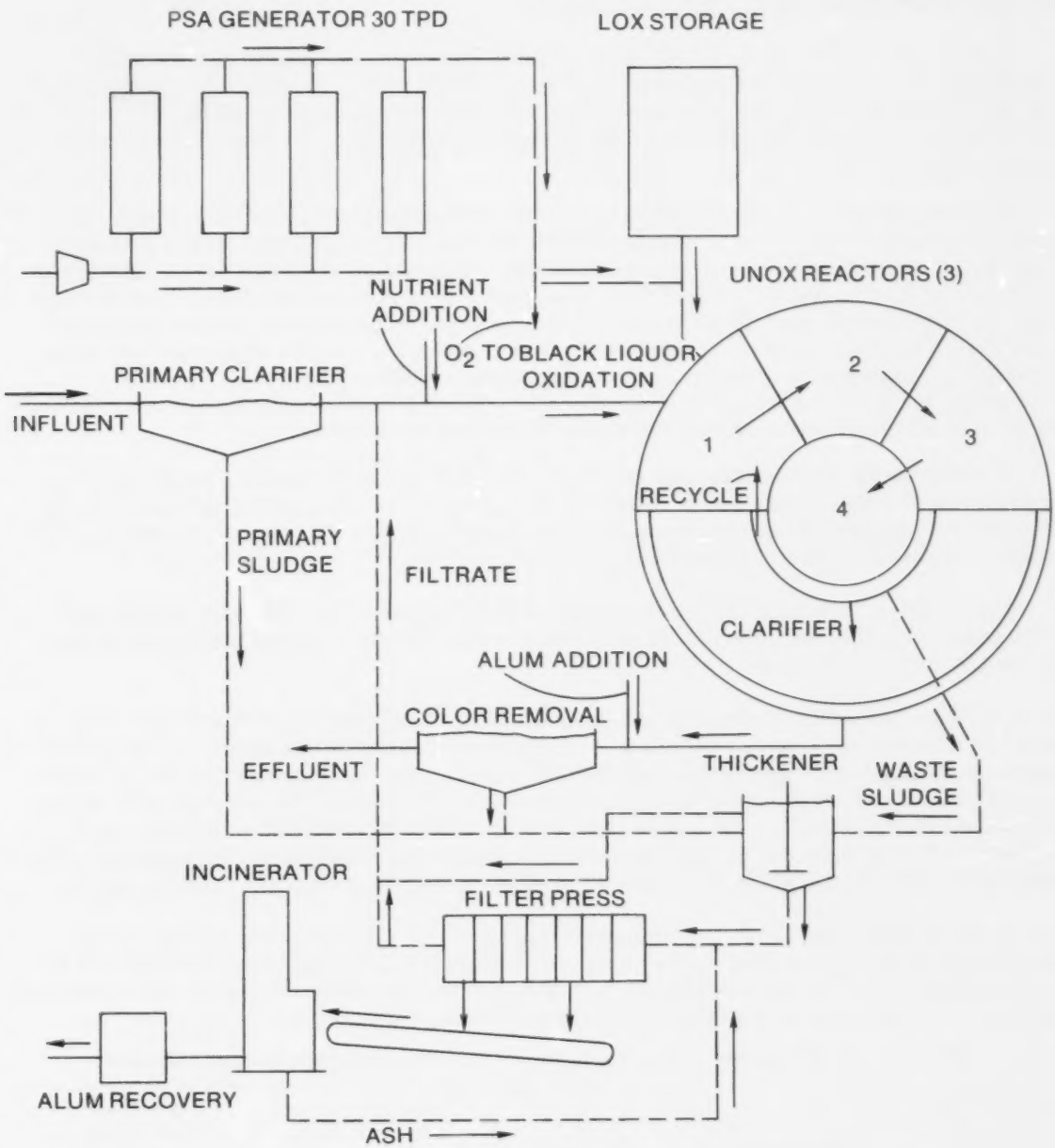

Figure 3-5. Flow diagram of the Gulf States Paper Corporation wastewater treatment plant - Tuscaloosa, Alabama.

Lederle Laboratories, Pearl River, New York

Lederle Laboratories, a division of American Cyanamid, manufactures pharmaceuticals, the majority of which are antibiotics. The waste stream resulting from production operations has a very high and variable organic carbon content. The plant wastewater flow which remains relatively constant at about 1.0 mgd (0.044 cu m/sec) can have a BOD_5 loading as high as 32,500 lb/day (14, 740 kg/day).

Prior to the spring of 1972, an air aeration system was used to treat plant wastes. The daily operations of this system were marked by persistent odor problems and inconsistent performance, arising from the highly variable organic load. A UNOX system was designed to replace the existing air aeration facilities. Start-up occurred in March 1972, which makes it the oldest permanent full-scale UNOX facility in existence.

A flow diagram of the new oxygenation treatment plant is given in Figure 3-6. The two-train reactor has overall dimensions of 148 ft long x 74 ft wide x 14.5 ft deep (45 m x 22.6 m x 4.4 m) with a SWD of 10 ft (3.0 m). The lead reactor stages are larger than the second or third stages to accommodate the high oxygen demand of the incoming wastewater. Polymers are added ahead of the single primary clariflocculator to lower the suspended solids concentration entering the secondary system as much as possible. The three circular secondary clarifiers each have a 40-ft (12.2-m) diameter, a 10-ft (3.0-m) SWD, and a plow-type sludge scraper. A 15-ton/day (13.6-metric ton/day) PSA generator and a 52-ton (47-metric ton) liquid oxygen backup tank provide oxygen supply.

Start-up difficulties included a foaming tendency which ceased once a good biomass had been established, and mixed liquor solids deposition caused by recycle of large amounts of lime and alum precipitates in the filtrate from the vacuum filter which are not effectively captured in the primary clariflocculator. Solids deposition was alleviated by adding bottom mixers to the initially supplied surface aerators. The PSA oxygen generator experienced upwards of 10 percent outage following start-up due to valve actuator problems. This unit was one of the first on-line molecular sieve applications geared to producing oxygen gas for wastewater treatment. As such, some experimentation was necessary to determine proper lubricating procedures for the valve actuators and to procure sufficienty rugged valve equipment to withstand rapid cycling. Following final modifications in mid-1973, total unscheduled PSA generator downtime has been reduced to less than one percent.

Odor complaints from neighboring residents numbered more than 80 in 1971. Complaints have not been received since the oxygen system went into operation.

A 50 percent sludge recycle rate has been necessary to prevent settled activated sludge from thickening to concentrations greater than 3-4 percent in the secondary clarifiers. During a three-month period when the recycle rate was decreased, the clarifier underflow concentration increased to 5-6 percent. Sludge pumping problems ensued at the higher concentrations, necessitating a return to the 50 percent rate.

Experienced flow have remained approximately one-third less than design. This has afforded Lederle the opportunity to remove one reactor train from service during summer months when the biochemical reaction rate is at its highest level. The partial shutdown action is taken to conserve energy during the time plant manufacturing energy requirements are greatest. During the remainder of the year, both trains are kept in service to minimize excess sludge production through operation at lower F/M loadings. None of the three secondary clarifiers are taken out of operation except for maintenance.

Average performance data for back-to-back test periods in 1972 are summarized in Table 3-5 for both one-train and two-train operation. Since the 1972 test period, sludge removal problems in the secondary clarifiers have been corrected. Settled sludge no longer fills up the secondaries and

spills over into the polishing clarifier. With the polishing clarifier serving in its intended role, effluent BOD_5 and suspended solids concentrations now generally average around 50 and 10 mg/1, respectively.

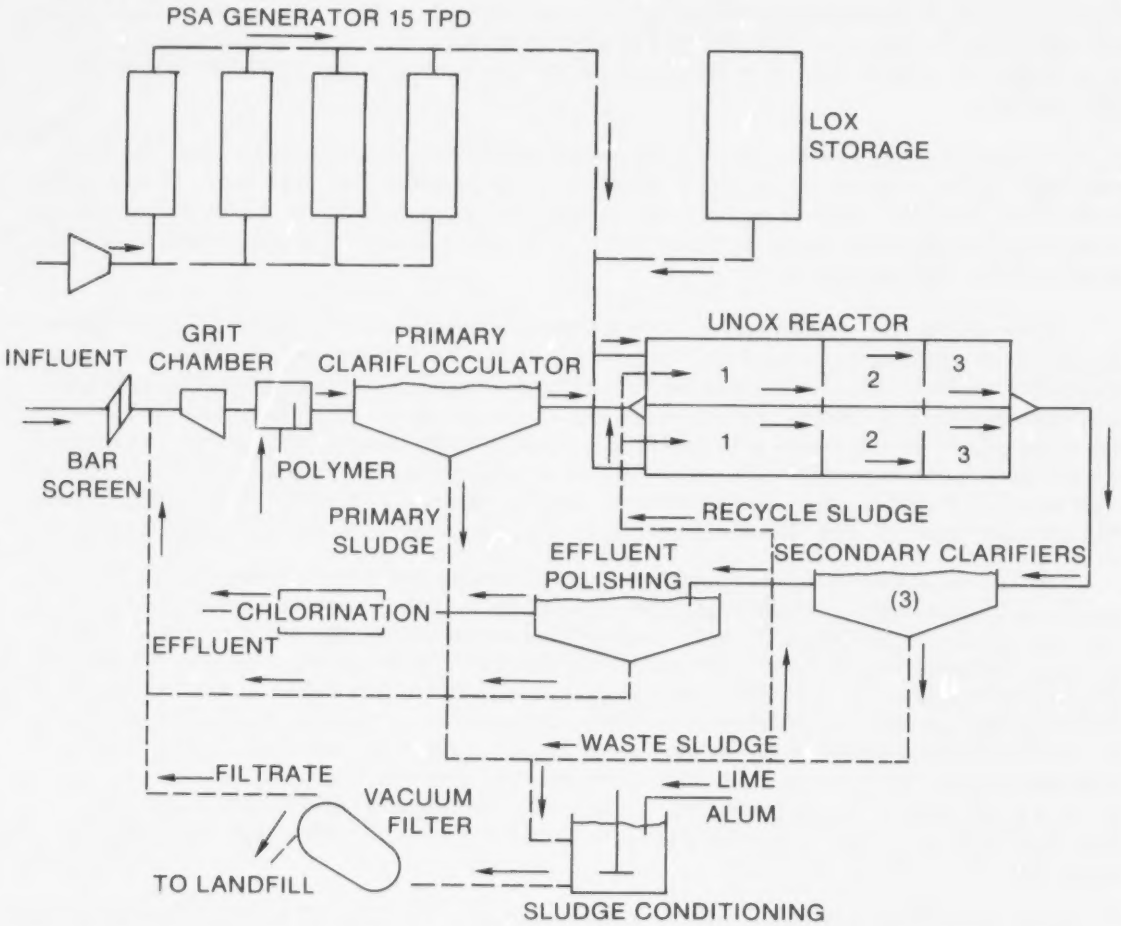

Figure 3-6. Flow diagram of Lederle Laboratories wastewater treatment plant - Pearl River, New York.

Table 3-5. ***Operating and Performance Data for Lederle Laboratories Oxygen System***

Parameter	Design	Operation	
		2 Trains Oct. 1972	1 Train Nov. 1972 (3 weeks)
Influent Flow (mgd)	1.5	1.0	1.0
Aeration Detention Time, Q (hr)	13	19.5	9.75
F/M Loading (kg BOD_5/day/kg MLVSS)	0.42	0.17	0.45
Secondary Clarifier Overflow Rate (gpd/sq ft)	540	360	360
MLSS (mg/1)	8000	11,500	9600
Return Sludge TSS (%)	2.8	3.5	3.0
Reactor Influent BOD_5 (mg/1)	1600	1400	1500
TSS (mg/1)	--	800	1300
Polishing Clarifier Effluent BOD_5 (mg/1)	160	80	90
TSS (mg/1)	--	70	60

Littleton, Colorado

The City of Littleton, Colorado, selected a modular UNOX system for a recent plant expansion. The modular unit used for Littleton is an off-the-shelf package system contained within one circular above-ground steel tank. The tank, 82 ft (25 m) in diameter x 15 ft (4.6 m) deep [SWD = 12 ft (3.7 m)], is divided by internal walls into a two-stage oxygen reactor, an arcuate secondary clarifier, a single-stage air aerobic sludge digester, and a chlorine contact chamber. The arcuate clarifier is equipped with floating bridge mounted air lift suction equipment for withdrawing settled sludge.

The new oxygen train operates in parallel with two existing trickling filters. Feed to the trickling filters is first settled in the plant's existing primary clarifier. The oxygen reactor receives raw degritted municipal wastewater directly. A flow diagram for the Littleton plant is presented in Figure 3-7.

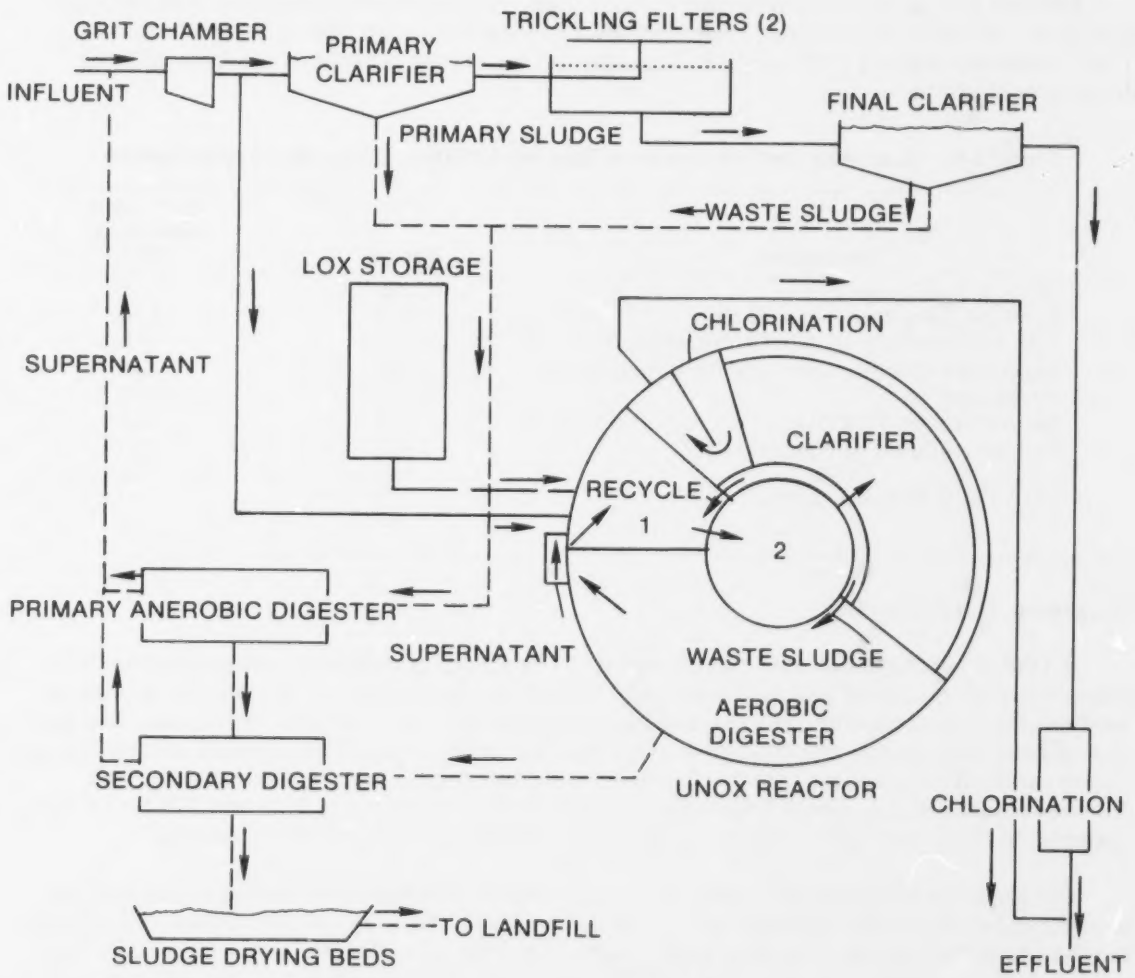

Figure 3-7. Flow diagram of Littleton, Colorado wastewater treatment plant.

The combined liquid volume of the two oxygen reactor stages is 97,000 gal (367 cu m). Surface aerators connected by shafts to bottom propellers are employed for oxygen dissolution and mixing. Due to the small size of the treatment plant, an on-site oxygen gas generating facility was not provided. Instead, liquid oxygen is trucked in and stored in a 43-ton (39-metric ton) tank, from where it is directed through an atmospheric vaporizer for conversion to the gaseous form before entering the oxygenation reactor.

The UNOX package system became operational in Feburary 1974. A major operating difficulty was immediately encountered. The original uncovered air aerobic sludge digester was equipped with mechanical surface aerators. Aerator icing occurred in the cold Colorado winter climate with resulting poor volatile suspended solids (VSS) reduction. The problem was rectified by installing a steel cover over the digester area along with urethane foam insulation and supplementing the surface aerators with an air blower and diffusers to provide adequate air circulation. VSS reductions have since ranged from 50-60 percent.

Influent flow to the oxygen portion of the Littleton plant has varied from 0.9 mgd (0.04 cu m/sec) to 1.4 mgd (0.06 cu m/sec) since start-up. The three-month average data summarized in Table 3-6 for the summer 1975 period indicate the oxygen system is performing within effluent design specifications.

Table 3-6. ***Operating and Performance Data for Littleton, Colorado Oxygen System***

Parameter	Design	Operation June-Aug. 1975
Influent Flow (mgd)	1.25	1.1
Aeration Detention Time, Q (hr)	1.9	2.16
F/M Loading (kg BOD_5/day/kg MLVSS)	0.6	0.6
Secondary Clarifier Overflow Rate (gpd/sq ft)	500	440
MLSS (mg/1)	5600	4000
Return Sludge TSS (%)	2.8	2.4
Reactor Influent BOD_5 (mg/1)	200	160
TSS	240	185
Secondary Effluent BOD_5 (mg/1)	20	12
TSS	25	24

Morganton, North Carolina

A UNOX facility designed to treat 8 mgd (0.35 cu m/sec) of municipal wastewater combined with substantial industrial contributions resulting from textiles production and poultry processing went on-stream at Morganton, North Carolina, in January 1975. As indicated in the plant flow diagram (Figure 3-8), primary clarification was not included in the design. The two-train oxygen reactor was constructed in an unusual box configuration with four stages per train. Each stage is 44 ft (13.4 m) square yielding overall length and width dimensions of 88 ft (26.8 m) and 176 ft (53.6 m), respectively. The total reactor depth is 14 ft (4.3 m) including a 4-ft (1.2-m) freeboard.

Oxygen system equipment consists of surface aerators with bottom impellers for oxygen dissolution and mixing and a 26-ton/day (23.6-metric ton/day) PSA generator and 28-ton (25.4-metric ton) liquid oxygen backup tank for oxygen supply. The PSA generator was outfitted initially with one one-half size compressor. A second half-size compressor will be added at a later date when plant flows increase. The two new secondary clarifiers are 80-ft (24.4-m) diameter units with 10-ft (3.0-m) SWD's and rapid sludge removal and grease skimming capabilities.

Process and mechanical reliability have been excellent in the year and half since start-up. PSA generator availability has exceeded 99.5 percent. A major operational problem in the form of high fat and grease loadings (often in excess of 100 mg/1) from the local poultry processor, however, has prevented consistent attainment of effluent quality objectives. No satisfactory method exists for rejecting these objectionable materials from the secondary system. The fat and grease which are only slowly bio-degradable pass to the final clarifiers and collect on the liquid surfaces. Although skimming devices were provided, much of the scum escapes the finals over the weirs taking with it significant quantities of enmeshed biofloc. Consequently, effluent suspended solids have reached levels as high as 80-100 mg/1. The problem is further accentuated by a hydraulic regime which transports final clarifier skimmings to the aerobic digesters and then recycles the digester skimmings to the plant headworks for recycle through the secondary system.

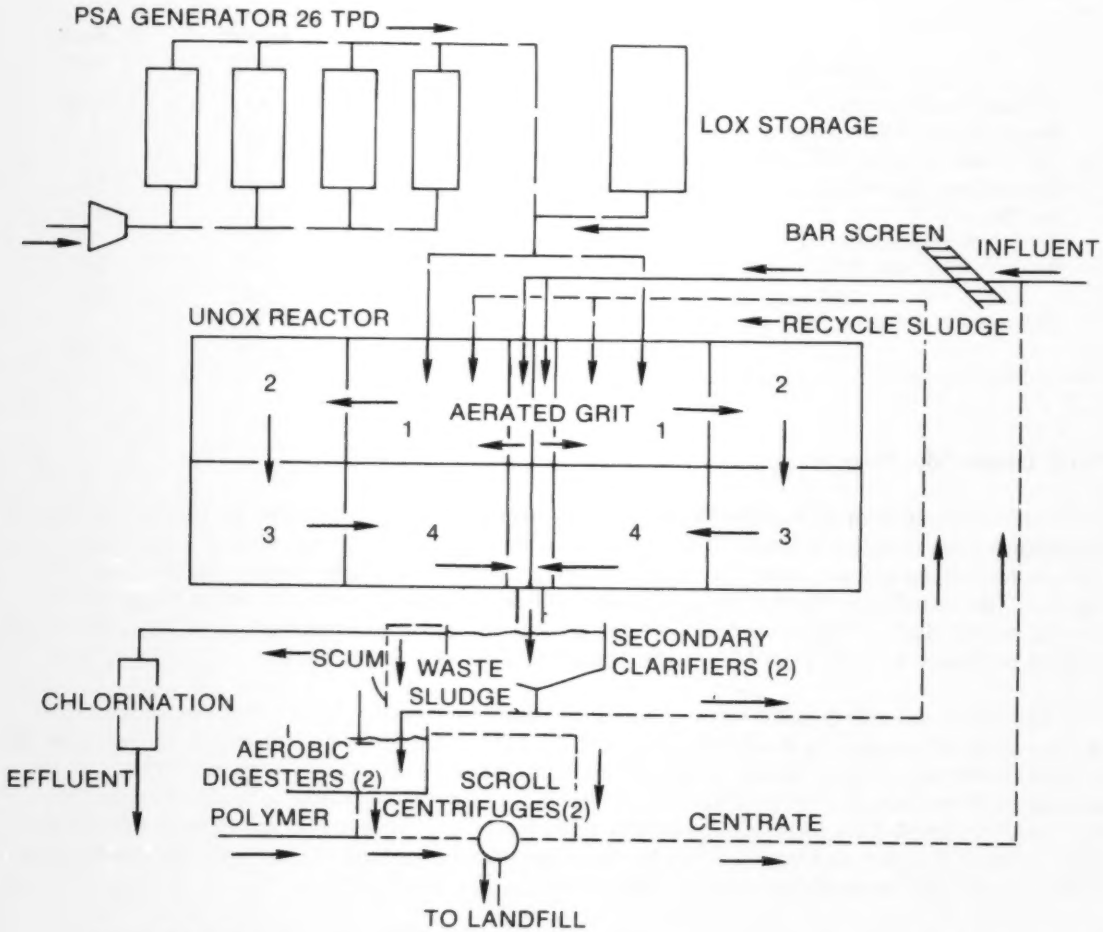

Figure 3-8. Flow diagram of Morganton, North Carolina wastewater treatment plant.

Efforts to remove a large fraction of the fat and grease load through pretreatment at the poultry processing site have been unsuccessful. Consideration is now being given to intercepting the skimmings from the aerobic digesters and disposing of them separately. When this technique has been evaluated for short periods on a trial basis, effluent clarity and suspended solids removals have improved measurably. The difficulties encountered at Morganton appear to the writer to constitute a compelling argument for the inclusion of primary clarification facilities in any future designs faced with similar wastewater characteristics.

Two months of operating and performance data are summarized in Table 3-7. Effluent quality documented for March 1975 is typical of months when the influent grease load has been somewhat lower than normal and represents about the best performance level that can be achieved under present conditions. In April 1975, the influent grease load was up, and the monthly average effluent suspended solids concentration increased accordingly. The much higher than anticipated influent suspended solids concentrations for these two months indicate that primary clarification would probably have been a desirable and justifiable feature aside from grease removal considerations.

Table 3-7. ***Operating and Performance Data for Morganton, North Carolina Oxygen System***

Parameter	Design	Operation	
		March 1975	April 1975
Influent Flow (mgd)	8.0	4.7	5.9
Aeration Detention Time, Q (hr)	3.5	6.0	4.7
F/M Loading (kg BOD_5/day/kg MLVSS	0.53	0.31	0.33
Secondary Clarifier Overflow Rate (gpd/sq ft)	800	470	590
MLSS (mg/1)	6000	5600	6400
Return Sludge TSS (%)	3.0	2.1	1.6
Reacotr Influent BOD_5 (mg/1)	350	364	357
TSS (mg/1)	400	836	946
Secondary Effluent BOD_5 (mg/1)	27	42	32
TSS (mg/1)	25	29	79

North Lauderdale, Florida

An off-the-shelf modular UNOX system was installed at North Lauderdale, Florida, to serve a population base of approximately 10,000 people. This package system consists of a two-stage oxygen reactor, an arcuate secondary clarifier, and an uncovered single-stage air aerobic sludge digester. The arcuate clarifier has an air lift suction device mounted from a floating bridge for removing settled sludge. The air aerobic digester is equipped only with mechanical surface aerators: it was not necessary to provide supplemental compressed air as at Littleton.

The entire secondary complex is contained within one circular, 95-ft (29-m) diameter, 15-ft (4.6-m) deep, above-ground steel tank. The tank's SWD is 12 ft (3.7 m). Unlike the Littleton modular unit, a separate external chlorine contact chamber was provided rather than including it in the package system. Granular media filters are available for effluent polishing, although to date they have not been used. Raw degritted municipal wastewater is fed directly to the oxygen system. Excess activated sludge is dewatered either by centrifugation or on sand drying beds. A flow diagram of the new North Lauderdale treatment plant is shown in Figure 3-9.

Oxygen dissolution and mixing are accomplished in the 129,000-gal (488-cu m) oxygen reactor with surface aerators and supplemental bottom agitators. A 43-ton (39-metric ton) liquid oxygen storage tank and attendant atmospheric vaporizer comprise the oxygen supply system.

The plant was placed in operation in early July 1975. To date, influent flow has been averaging only about 65 percent of the design flow of 2 mgd (0.09 cu m/sec), although wastewater strength has been somewhat higher than anticipated. No significant operating problems have been encountered. Performance as exhibited by the average data for September 1975 shown in Table 3-8 has been excellent.

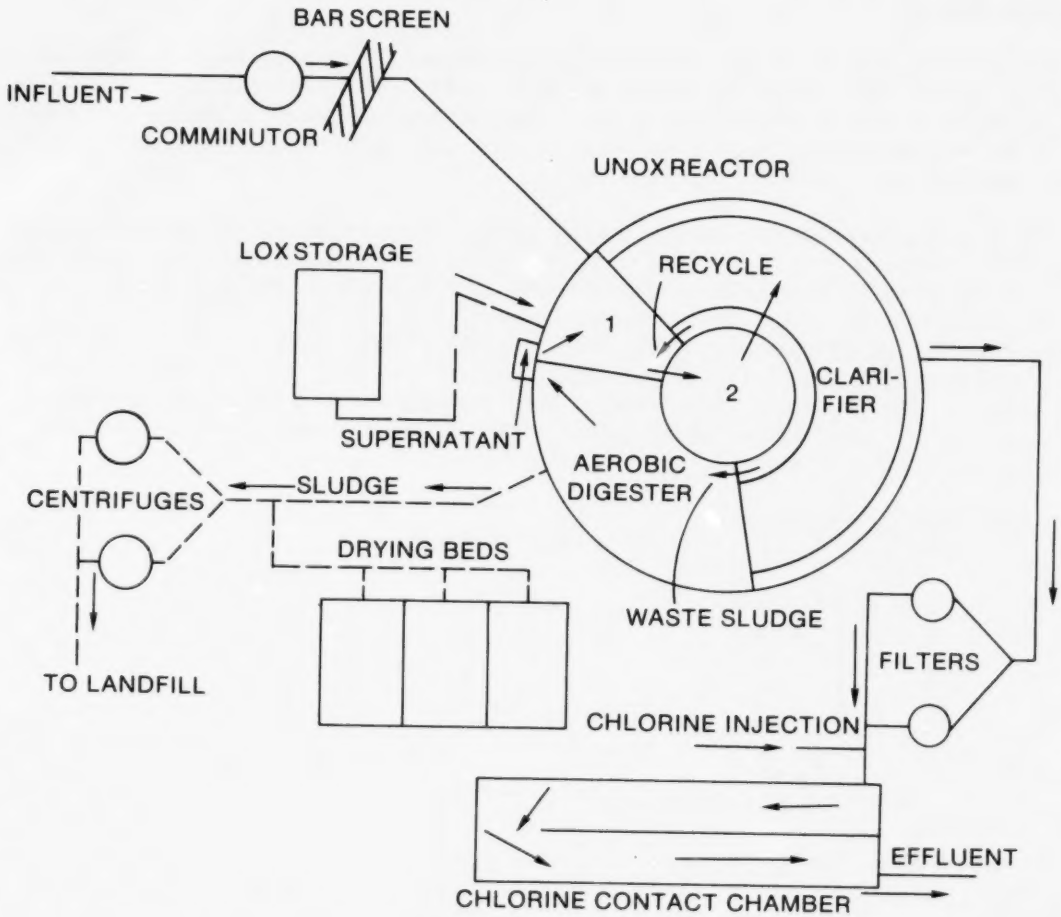

Figure 3-9. Flow diagram of North Lauderdale, Florida wastewater treatment plant.

Table 3-8. ***Operating and Performance Data for North Lauderdale, Florida Oxygen System***

Parameter	Design	Operation Sept. 1975
Influent Flow (mgd)	2.0	1.3
Aeration Detention Time, Q (hr)	1.56	2.4
F/M Loading (kg BOD_5/day/kg MLVSS)	0.68	0.68
Secondary Clarifier Overflow Rate (gpd/sq ft)	525	541
MLSS (mg/1)	5600	4500
Return Sludge TSS (%)	2	1.5‡
Reactor Influent BOD_5 (mg/1)	200	245
TSS (mg/1)	130	180
Secondary Effluent BOD_5 (mg/1)	20	<10
TSS (mg/1)	20	<10

‡High return sludge rate

Speedway, Indiana

In June 1972, a new 7.5 mgd (0.33 cu m/sec) UNOX installation was placed in operation at Speedway, Indiana. This was the first municipal UNOX facility to be completed. Of all the oxygen-activated sludge wastewater treatment systems now in operation, the Speedway plant was preceded only by the municipal OASES plant at Fairfax County, Virginia, and the industrial UNOX plant at the Lederle Laboratories in Pearl River, New York.

The flow diagram in Figure 3-10 indicates that the Speedway oxygen system is of conventional design. The two-train oxygen reactor is preceded by primary clarification. Three of the six primaries are existing units; the other three are converted secondary clarifiers from the City's old trickling filter treatment facility. Each of the four reactor stages per train is 22 ft (6.7 m) square with a 16-ft (4.9-m) SWD. The overall dimensions of the two reactor tanks taken together are 88 ft long x 44 ft wide x 20 ft deep (26.8 m x 13.4 m x 6.1 m). Three new 65-ft (19.8-m) diameter, 10-ft (3.0-m) SWD secondary clarifiers with the increasingly popular rapid method of removing settled sludge were provided. At a future data as needed, plant capacity can be increased to 10 mgd (0.44 cu m/sec) by the construction of one additional secondary clarifier.

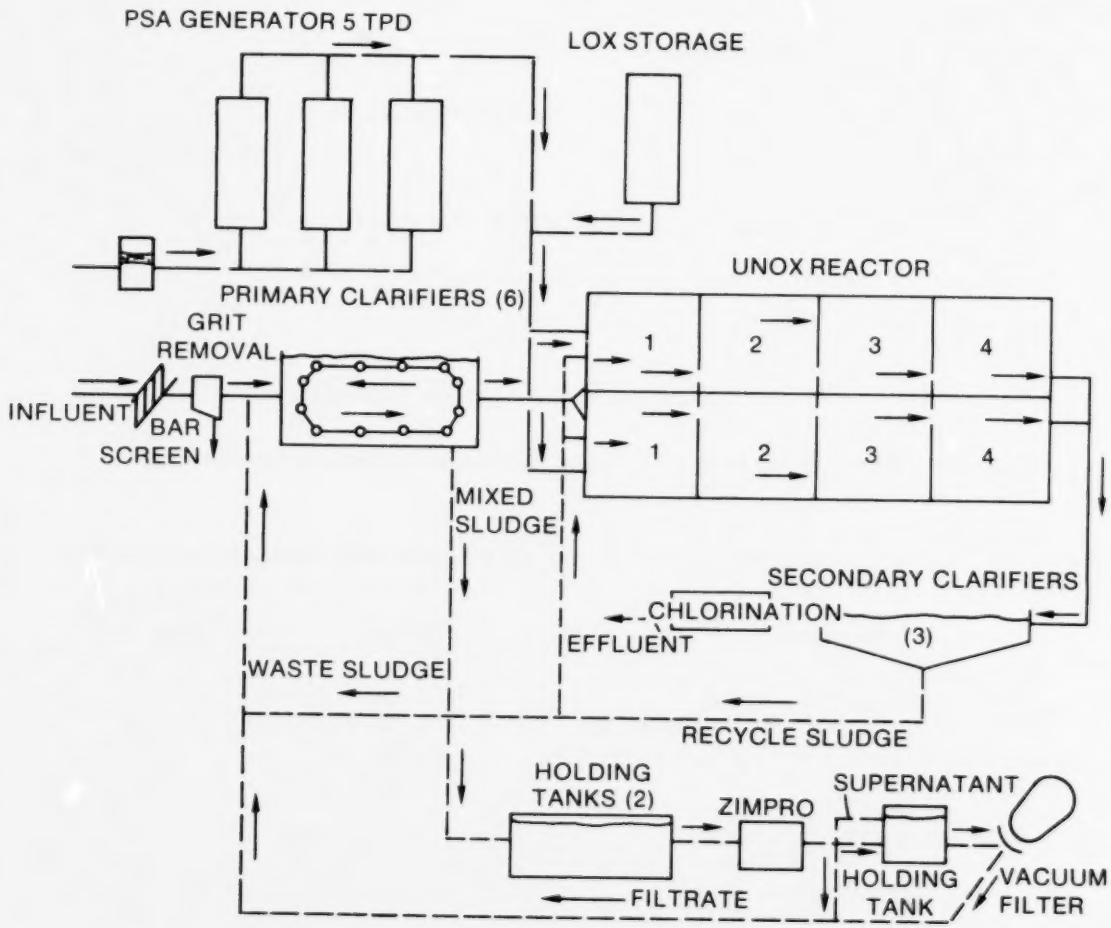

Figure 3-10. Flow diagram of Speedway, Indiana wastewater treatment plant.

The UNOX reactors were designed to use surface aerators attached by shafts to bottom agitators for oxygen dissolution and mixing. A three-bed 5-ton/day (4.4-metric ton/day) PSA unit generates oxygen gas on-site. A 7-ton (6.4-metric ton) liquid oxygen storage tank and accompanying atmospheric vaporizer were furnished for reserve. Profiting from difficulties experienced with earlier four-bed PSA generator designs at Lederle Laboratories and on a U.S. EPA co-sponsored demonstration grant project at the Newtown Creek plant in Brooklyn, New York (3), particularly as related to valves and lubricants, the second generation three-bed design employed at Speedway has proven to be highly reliable with less than 1-1/2 percent total downtime for scheduled and unscheduled maintenance.

Waste activated sludge is recycled to the primaries for co-thickening with raw sludge. The mixed sludges are then pumped to a holding tank which feed a Zimpro wet oxidation system designed to condition sludge for dewatering. Conditioned sludge is dewatered by vacuum filtration prior to being trucked to landfill. Periodic and lengthy shutdowns of the wet oxidation system placed considerable stress on the main stream treatment components for much of the early history of this new facility. Unable to truck liquid sludges away, it was frequently necessary to return mixed raw and waste sludges from the sludge holding tank to the primary clarifiers. When the primaries filled up, sludge overflowed into the oxygen reactors along with primary effluent. The oxygenation tanks during these periods in effect served more as aerobic sludge digesters than conventional activated sludge systems.

Considering the difficulties imposed by the above conditions on the management of secondary sludge inventory, oxygen system performance was superb. Annual average effluent BOD_5 and suspended solids concentrations were low in both 1973 and 1974, as indicated in Table 3-9. The highest monthly average BOD_5 and suspended solids levels recorded in these two years were 16 and 30 mg/1, respectively. Also shown in Table 3-9 are the results of one month of one-train operation in early 1976. Occasional one-train operating tests have been conducted by plant personnel to evaluate oxygen system performance at loadings comparable to design values.

Table 3-9. ***Operating and Performance Data for Speedway, Indiana Oxygen System***

Parameter	Design	Operation		
		2 Trains*		1 Train†
		1973	1974	Jan. 16 - Feb. 18, 1976
Influent Flow (mgd)	7.5	4.4	4.6	4.3
Aeration Detention Time, Q (hr)	1.48	2.52	2.41	1.29
F/M Loading (kg BOD_5/day/ke MLVSS)	0.51	0.20	0.51	0.70
Secondary Clarifier Overflow Rate (gpd/sq ft)	750	440	460	645
MLSS (mg/1)	4200	6080	6600	4760
Return Sludge TSS (mg/1)	2.2	1.54	1.3	1.66«
Reactor Influent BOD_5 (mg/1	110	91	73	114
TSS (mg/1)	96	179	109	118
Secondary Effluent BOD_5 (mg/1)	15	9	9	13
TSS (mg/1)	20	16	14	18

*Three secondary clarifiers in operation
†Two secondary clarifiers in operation
« Excludes reported values for Feb. 6, 7, 8 and 9

Union Carbide Corporation, Sistersville, West Virginia

The Chemicals and Plastics Division of the Union Carbide Corporation placed a UNOX system in operation in November 1973 to treat waste products from the manufacture of silicones. The resulting wastewater stream has a high organic carbon content and also contains substantial quantities of acid and various oils. Conditioning is necessary ahead of the biological process to neutralize the acid and remove the oil. A holding pond (not included in the flow diagram shown in Figure 3-11) is utilized for diversion of large spills that cannot be adequately preconditioned.

This inhouse Carbide project marked the first utilization of circular reactor/clarifier UNOX combination tanks. Two such units were installed, each consisting of three arcuate reactor stages and one circular reactor stage and an arcuate final clarifier. In contrast to the above-ground designs employed in later circular UNOX facilities (refer to Gulf Stages Paper Corporation; Littleton, Colorado; and North Lauderdale, Florida), the Sistersville tanks were installed in conventional below-ground fashion. The custom-designed dimensions of the Sistersville units are: diameter – 102 ft (31.1 m), total depth – 14 ft (4.3 m), and SWD – 10 ft (3.1 m). The final clarifiers are equipped with airlift suction equipment for removing settled sludge.

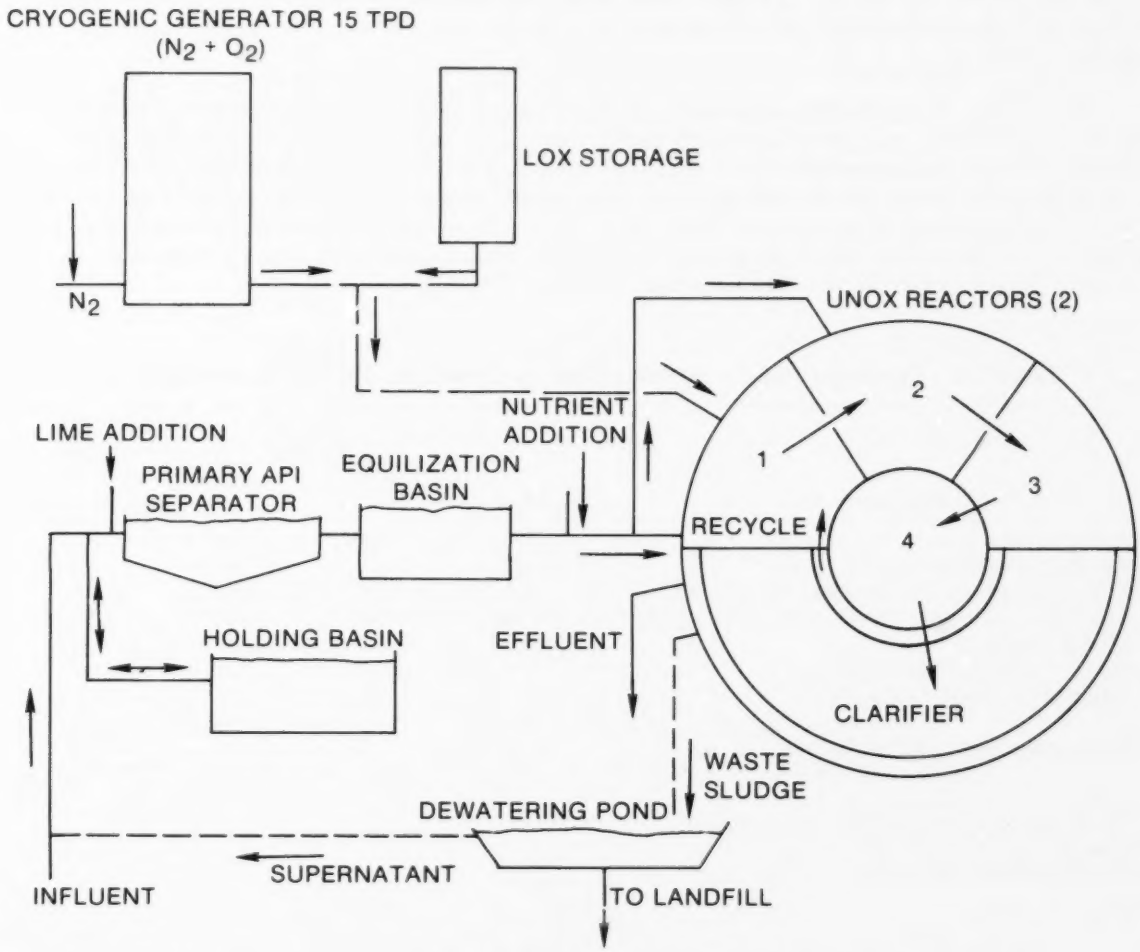

Figure 3-11. Flow diagram of Union Carbide Corporation wastewater treatment plant - Sistersville, West Virginia.

Surface aerators connected to bottom impellers are used to achieve oxygen dissolution and oxygen and biomass dispersion. Oxygen is supplied in a rather unusual manner from an on-site industrial cryogenic nitrogen gas generator which produces 15 tons/day (13.6 metric tons/day) of oxygen gas as a by-product. Prior to start-up of the silicones wastewater treatment facility, the by-product oxygen was wasted to the atmosphere.

Problems were initially encountered with the floating bridge mechanism from which the sludge scraping and pickup devices are supported. Corrective action required redesign and relocation of the bridge center support. Later arcuate clarifier designs profited from the Sistersville experiences.

Occasional toxic spills, primarily from copper, have resulted in biological upsets. The oxygen-activated sludge system has usually recovered from these spills within one week. Following an in-plant survey, a program is underway to eliminate copper from plant discharges in concentrations which are toxic to microorganisms.

Average monthly operating and performance data for August and December 1975 are presented in Table 3-10. At influent loadings equal to 85-95 percent of hydraulic capacity, effluent quality has been significantly better than required by the design specifications. The difficulty in settling silicone fines can be noted in the effluent suspended solids levels which are two to three times the effluent BOD_5 concentrations.

Table 3-10. ***Operating and Performance Data for Union Carbide Sistersville Oxygen System***

Parameter	Design	Operation	
		Aug. 1975	Dec. 1975
Influent Flow (mgd)	4.3	3.6	4.1
Aeration Detention Time, Q (hr)	3.5	4.2	3.7
F/M Loading (kg BOD_5/day/kg MLVSS)	0.85	0.75	0.90
Secondary Clarifier Overflow Rate (gpd/sq ft)	600	502	572
MLSS (mg/1)	5000	4500	3900
Return Sludge TSS (%)	2.0	1.0‡	2.0
Reactor Influent BOD_5 (mg/1)	370	425	339
TSS (mg/1)	<100	75	103
Secondary Effluent BOD_5 (mg/1)	50	25	20
TSS (mg/1)	<100	70	43

‡High sludge return rate

Winnipeg, Manitoba

One of the more attractive oxygen-activated sludge plants now in operation is located at Winnipeg, Manitoba, Canada. This 12-mgd (0.53-cu m/sec) treatment facility was designed to operate over a wide air temperature range (100° F in summer to -50° F in winter) and is, therefore, totally housed with the exception of the covered UNOX reactor.

The plant utilizes a conventional flow scheme to treat municipal wastewater. Primary clarification is utilized ahead of a two-train, three-stage/train, oxygenation reactor having overall dimensions of 120 ft long x 60 ft wide x 19.5 ft deep (36.6 m x 18.3 m x 5.9 m). The reactor's SWD is 16 ft (4.9 m). Mixed liquor flow is evenly divided between two 110-ft (33.5-m) diameter final clarifiers. The SWD of the finals is 10 ft (3.0 m). As with most recently-constructed circular clarifiers, rapid sludge removal equipment was provided rather than the older plow-type scrapers. Primary and waste activated sludges are mixed and centrifuged before undergoing incineration. The flow diagram for the plant is given in Figure 3-12.

The UNOX system components selected for Winnipeg includes surface aerators and bottom mixers for oxygen dissolution and a 10-ton/day (9.1-metric ton/day) PSA oxygen gas generator and 14-ton (12.7-metric ton) liquid oxygen backup tank for oxygen supply. Considerable difficulty has been experienced with the operation of the PSA compressor. This machine was initially outfitted with internal clearance pocket unloaders. These unloaders did not function properly resulting in the imposition of undue stress on and excessive wear of compressor bearings and bushings. Frequent outages were necessary to overhaul the worn parts. Eventually in late 1975, the compressor was completely rebuilt and the clearance pocket unloaders replaced with suction pocket unloaders. Except for one subsequent unscheduled outage due to a heater failure, the compressor has worked well since then.

System start-up occurred in September 1974. No process related difficulties have been encountered. Operation at cold mixed liquor temperatures down to 10° C has not induced growth of filamentous organisms or any other noticeable sludge settling problems. In each 1975, official one-month performance tests were conducted with only one reactor train in service and with both reactor trains in service. Both final clarifiers were used during each test. The results of the tests are documented in Table 3-11. In each case, although the aeration detention time was less than the F/M loading higher than design, effluent BOD_5 and suspended solids concentrations were significantly lower than required by design stipulations.

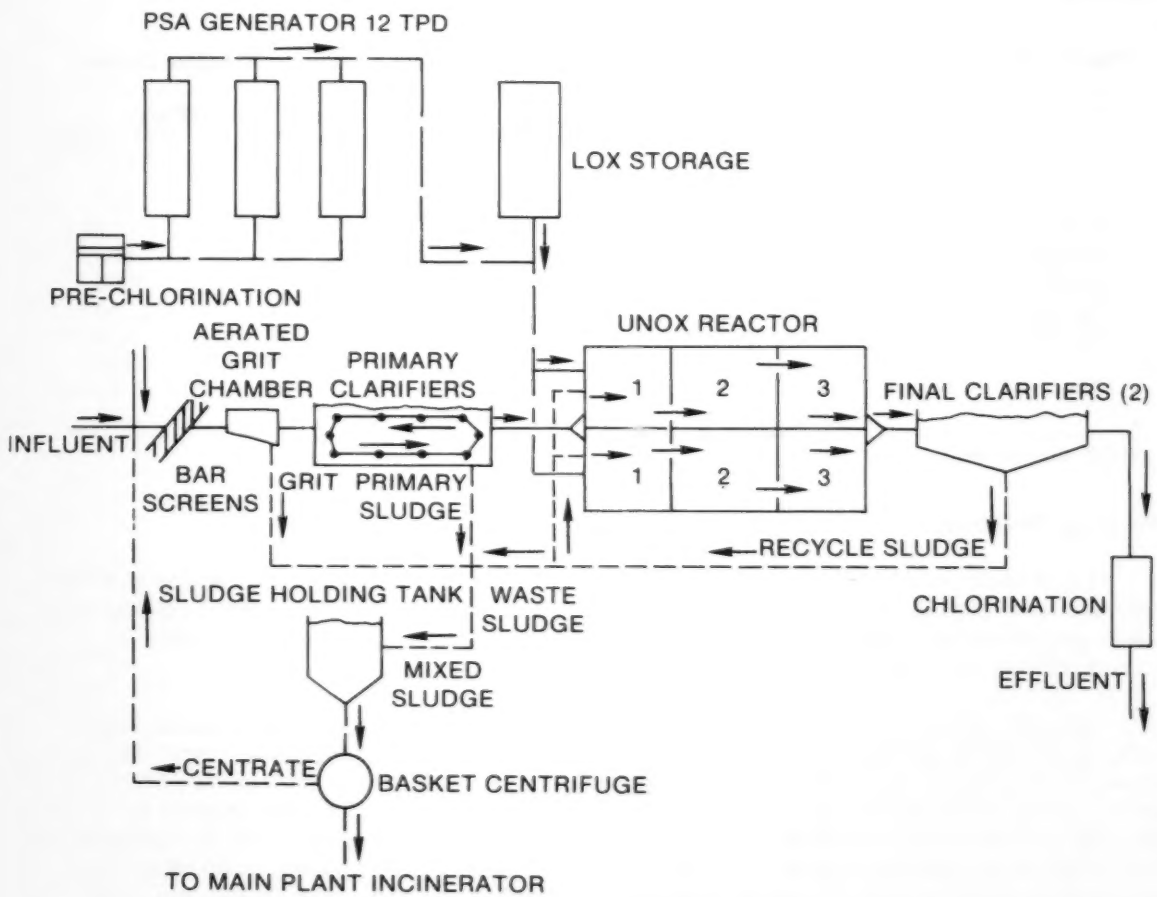

Figure 3-12. Flow diagram of Winnipeg, Manitoba wastewater treatment plant.

Table 3-11. ***Operating and Performance Data for Winnipeg, Manitoba Oxygen System***

Parameter	Design	Operation	
		1 Reactor Train‡ Jan. 1975	2 Reactor Trains‡ Apr. 1975
Influent Flow (mgd)	12	8.5	13.4
Aeration Detention Time, Q (hr)	1.74	1.23	1.59
F/M Loading (kg BOD_5/day/kg MLVSS)	0.46	0.99	0.62
Secondary Clarifier Overflow Rate (gpd/sq ft)	630	446	704
MLSS (mg/1)	5000	5950	5100
Return Sludge TSS (%)	2.2	1.9	1.6
Reactor Influent BOD_5 (mg/1)	133	244	150
TSS (mg/1)	100	290	193
Secondary Effluent BOD_5 (mg/1)	25	20	17
TSS (mg/1)	30	17	13

‡Both final clarifiers in service

INFORMATION SOURCES

Information on oxygen systems in various stages of implementation was supplied by the Union Carbide Corporation; Air Products and Chemicals, Inc.; and the FMC Corporation. Case history data and flow diagrams for UNOX plants in operation were provided by the Union Carbide Corporation. Case history data and pertinent diagrams for the OASES plant at Fairfax County, Virginia, were extracted from the final report for U.S. EPA Contract No. 68-03-0405. Process design and equipment criteria for and visual representations of the MAROX process were taken from FMC Corporation advertising literature (4), supplemented by information derived from personal communications with FMC. Progress reports and other information on file at the U.S. EPA's Municipal Environmental Research Laboratory for Grant No. S803910 formed the basis of the discussion of Metropolitan Denver's MAROX demonstration project. Flow and dimensioned diagrams of the Denver MAROX test bay were reprinted from an FMC project bulletin (6).

The assistance of staff members of the above three firms who contributed in supplying the above described information is gratefully acknowledged. The cooperation of Richard Kaptain, Assistant Plant Manager for the City of Decatur, Illinois, in providing additional details for the Decatur UNOX case history is also appreciated.

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